1. Introduction

Chapter 1 will contain the introduction, the problem definition, the goal and objectives and in the end will explain the report-structure.

1.1. Introduction

1.1.1. Challenges for an ageing population

The Dutch population is getting older. In 2014, 18% of the population was older than 65. In 2040 the demographic ageing will reach its top, 26% of the population will be 65 years and older. [24] Amsterdam has less demographic ageing compared to the whole of Netherlands [24]. 22.4% of its inhabitants is older than 55, in absolute numbers 182.000 inhabitants on 01-01-2014. See figure 1.1. One fifth of these elderly is older than 75 and 13% older than 80. [24] By 2040, Amsterdam will have 11 to 16 percent more elderly inhabitants of above the age of 65.

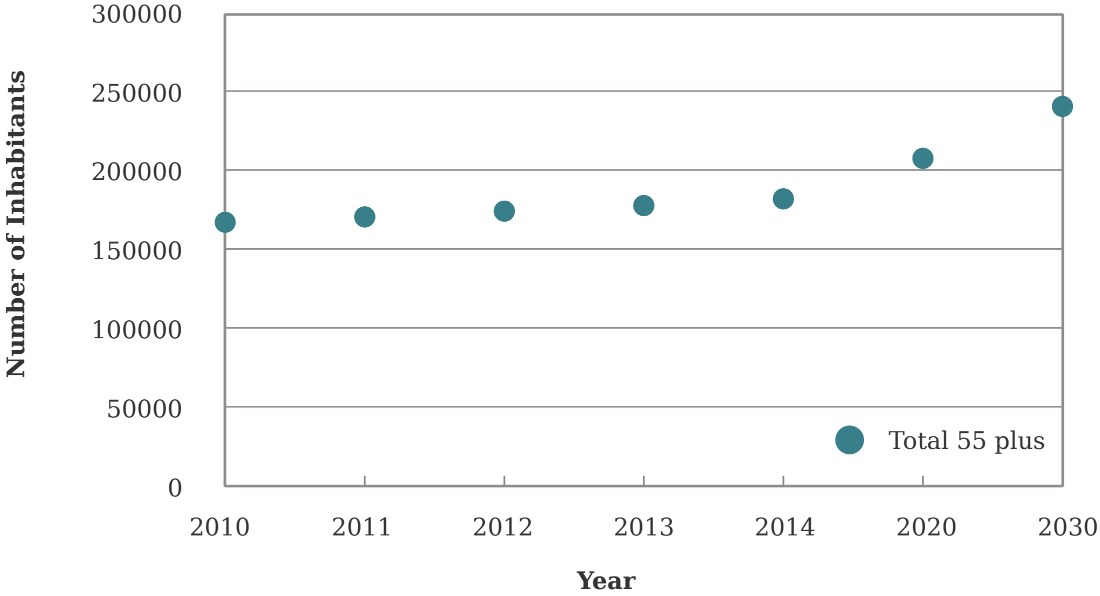

Figure 1.1.: Total 55 plus inhabitants Amsterdam. On the 1st of January 2010-2014 & Prognosis (2013) for 2020 and 2030. (Hylkema et al. 2014)

Since 2015 the Dutch municipalities are responsible for the care of elderly, the assistance and support. The growing share of elderly is expected to demand higher funds regarding health care, social care and retirements wages but fewer funds are available for decentralized governments to spend on health care. These developments challenge to seek solutions to balance cost and services. Synergizing policy solutions between different policy areas at a decentralized level may help with the solution. [24]

The new trend in elderly care is letting elderly live longer independently [31, 43] also called active ageing [5]. The Amsterdam municipality aims its elderly strategy in the StructuurVisie for 2040 to let older inhabitants live independently, as long as possible, to reduce health care costs. Growing old in the own house, is welcomed by a lot of older inhabitants of Amsterdam. [11]

1.1.2. Elderly pedestrians

Living independently means being mobile for personal care and have access to the public space for grocery shopping, social contacts and physical activity. In urban areas, elderly depend on walking for their everyday life and it is a key aspect of daily life to stay independent. [21]. Walking as form of transport happens more in urban areas then in rural(figure 1.2). In many countries 30 to 50% of older people's journeys outside are made as a pedestrian [39]. In the Netherlands about 23% of the trips made by elderly are made by foot. In Amsterdam 31% of the main trips are made by foot. In general, Dutch elderly depend more on walking then other age groups as seen in figure 1.3 from a pedestrian study by CROW(explained in section 1.2.1). [29, 38, 14]

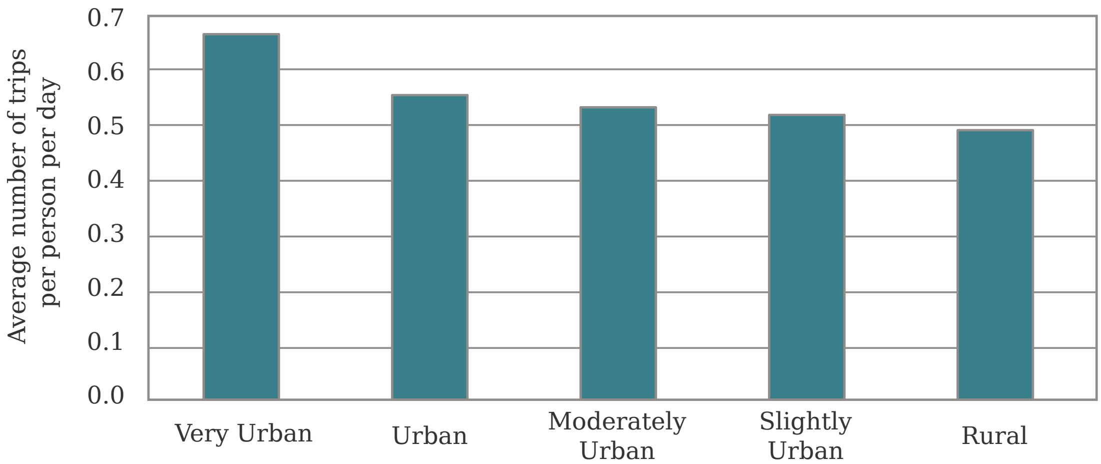

Figure 1.2.: Walking trips made in specific environment. (Sauter et al. 2010)

The main benefit of walking is the importance for the health of elderly. [10] Regular exercise has a positive effect on the fitness and physical health. Also lowering stress and improves the overall well-being. There is a well-established correlation between health benefits and regular physical activity. [5] Also, for elderly walking is the favoured form of physical activity. [10] See figure 1.3.

In conclusion, outdoor physical activity, particular walking, seems the key role in the maintenance of functional independence at old age. [34] By enabling mobility, elderly can keep control of their own life by being able to move outside independently for everyday tasks and social contacts. [31] Walking keeps them fit and healthy and so increases the chance of longer and independent life. Overall, contributing to a better quality of life.

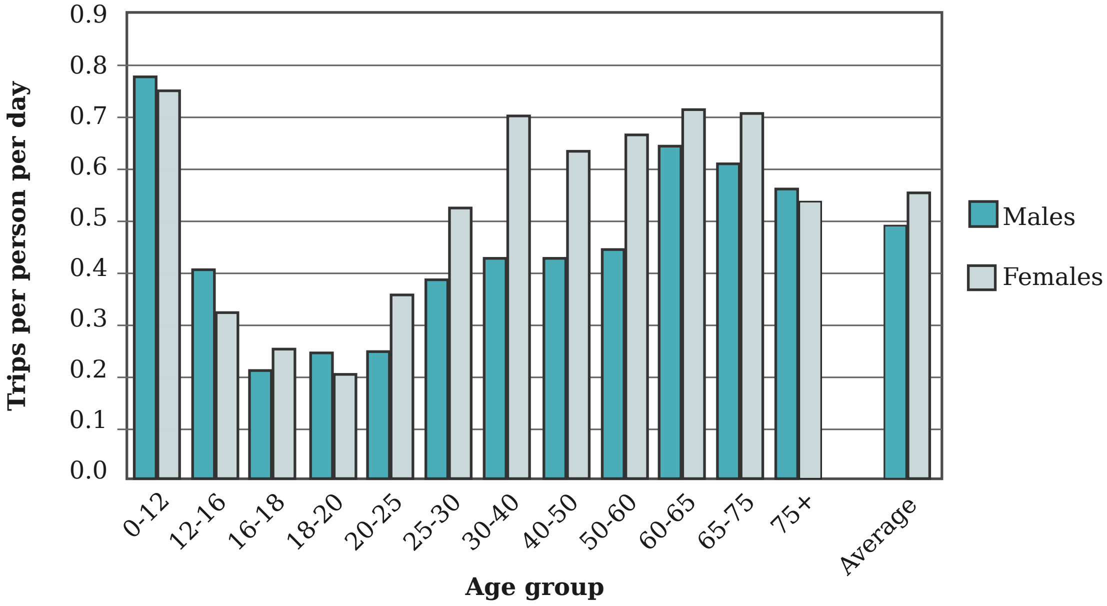

Figure 1.3.: Number of trips per person per day by age group. (NL, 2007 from [35])

1.1.3. The Rollator

A lot of elderly use a rollator, or wheeled walker. It helps maintaining mobility and continuing an active lifestyle. It provides stable support and may help avoid falls. Walkers are an important assistant for elderly who face difficulty walking and maintaining balance. The exact amount of rollator users in the Netherlands is unknown. An estimation in 2002 states 160.000 to 300.000 rollator users in the Netherlands [45] with an average age of 77.7 years according to an article in Trouw. [15] For further references we will refer to the wheeled walker as a rollator indicating a hand held walker with four wheels.

1.1.4. Mobility problems

Getting older means; being less mobile and more fragile. [45] In general, about 50% of the pedestrians in the Netherlands have limited mobility abilities and around 10% of the population has severe difficulties walking and sojourning in the public space. [38] Table 1.1 shows the number of Dutch inhabitants with limited mobility, with the largest group formed by elderly above 65. Also the prediction for 2030 shows an increase in elderly with mobility problems. [38]

Yearly 18.000 elderly of above 55 need emergency care after a fall on the street. This means that every 30 minutes an elder adult falls so severe that care in the emergency room is needed. [45] About 2.300 elderly of above 55, need emergency care after a fall with a rollator. [45] One of the six falls with a rollator is outdoors. (380 falls a year) [45]

Falls on the street without rollator occur more than falls with a rollator (18.000 to 2.300), but the latter cause more severe injuries. The medical costs for a fall with a rollator are inexplicably higher than a normal fall on the street(table 1.2). An indication that a fall with a rollator leads to more serious injuries, then a fall with bike or scoot-mobile. [45]

Fall accidents on the street occur due to behavioural factors (61%) and environmental factors (58%). Falls with a rollator can occur because a walker may be difficult to handle, the rollator is unstable or too heavy to handle for the user. A user needs strength and coordination to operate a rollator effectively [19, 49]. Environmental influences noted are irregular surface (43%), obstacles and irregularities (31%), bad maintenance (16%) and slippery areas (13%). [45] One third of the falls on the street is because an elderly tripped (35%) over a stone or tile (10%) or a curb (4%) and one fifth slipped (20%) on a slippery surface (12%). [45]

Table 1.1.: Predicted number of people with limited mobility, Netherlands (Sauter et al. 2010)

-	2005	2010	2015	2020	2025	2030
Perc of people w limited mobility	6.1	6.3	6.7	7.0	8.2	9.4
Number Younger than 65	340.000	340.000	350.000	350.000	360.000	360.000
Number 65 - 79	250.000	270.000	310.000	360.000	400.000	430.000
Number 80+	410.000	430.000	460.000	490.000	660.000	830.000
Total number	990.000	1.050.000	1.130.000	1.200.000	1.410.000	1.620.000

Table 1.2.: Yearly average and total medical costs for 55+, to type of accident. From Letsel Informatie Systeem 2006-2010, VeiligheidNL [16]

	Average costs	Total costs
Private- and traffic accidents on the street	€ 4.500	€ 220m
Fall on the street	€ 4.200	€ 82m
Simplex bicycle accident	€4.600	€ 71m
Rollator	€12.000	€ 33m
Scoot mobile	€ 6.900	€ 8,9m

1.1.5. The contribution of the built environment to walkability

For elderly, who are more vulnerable, environmental attributes can be barriers to an active engagement in urban life. The quality of the immediate environment is a significant determinant of elders well-being, independence and quality of life. [47] Because these environmental details are critical for what the older inhabitants can manage in their everyday lives [39, 41, 13, 5] creating a walking-friendly environment is important for their independent mobility. [38] The few studies that explore the older inhabitants and pedestrian-ism are arguing that good neighbourhood design can influence physical activity, health and consequently can lead to a longer life time of independence. [47, 34, 33, 8, 37, 13] The environment can have a powerful effect on the amount of walking activity undertaken by older people, thereby influencing their capacity to maintain their well-being and independence [47].

The assessment of a neighbourhood design that supports elderly can be based on walkability.

Walkability is the measure of how friendly the environment is to walking. The extent to which the built environment supports and encourages walking. By being friendly, giving comfort and safety, and provide aesthetic appeal. [47, 10]

A report from CROW, which is further explained in the next section, about pedestrianism in the Netherlands states that investing in pedestrian policy and making a pedestrian-friendly environment lets the elderly live longer independently. [29, 14] This means, it requires the environment to provide the best conditions for even the most frail and weak sub-group.

Previous studies have found a relationship between neighbourhood characteristics, physical activity and related health aspects. [10] Aspects of the built environment, in particular neighbourhood design, have been found to influence the amount of physical activity undertaken by inhabitants of urban neighbourhoods, [10] access to public transport, nearby goods and services, walking for leisure, social interaction and engagement in the community. [47] In order to increase the quality of the environment, we need better insight into the influence of the urban design on the walking behaviour of elderly to make it useful for policy and design.

1.2. Problem definition

1.2.1. The forgotten pedestrian in policy

There is little research carried out on pedestrian satisfaction in the Netherlands. The sparse information about what dissatisfies the pedestrian comes from complaints at local authorities, questionnaires or internet sites. The Pedestrian Quality Needs Project(PQN), identifies what people need for safe mobility in the public space. The project was conducted from November 2006 until November 2010. The main objective was to provide knowledge of pedestrians' quality needs to support walking conditions it the EU. They provide an extensive report on what people require as a pedestrian, and reports stating the current status of pedestrian knowledge in all participating countries. [38] The PQN report of 2010 on walking in the Netherlands states that serious problems and deficits in Dutch pedestrianism are partly or totally hidden from public, scientific and political attention. [35] They state the following about pedestrian knowledge in the Netherlands:

The vicious circle of no data- no awareness - no priority - no research - no data, needs to be broken. [38, 35]

With specific regard to elderly the PQN report states that large numbers of people already have trouble performing walking and sojourning tasks and because of the ageing of the population these numbers will only increase. [38] Therefore, prevention of falls is important in regard to the safety of pedestrians which is also an age related problem. [38]

The publication about pedestrians in the Netherlands from CROW (2014) [14], states that pedestrians are forgotten in policy and design. CROW is a national knowledge platform for infrastructure, traffic, public transport and public space. A non-profit organisation providing guide-lines for the design, policy and projects with regard to the design of the public space. They state that walking, though one on the main forms of transportation, gets less attention then bicycles, public transport and cars. Pedestrians get more easily forgotten in policy design and maintenance plans. There is a need for a more systematic approach. [14] There are two reasons why walking is not part of policy and design plans; first, there is a lack of knowledge about how investments contribute to the tackle of problems. Second, there is no insight how walking can be optimised in policy, design and maintenance plans. [14] With regard to elderly as pedestrians in specific, they state, that a well accessible pedestrian network, and attractive walking routes can contribute to the independence of elderly. Children and elderly are vulnerable in traffic, and elderly pedestrians above 75 have the biggest risk of being victim to traffic accidents with severe endings. [14]

MENSenSTRAAT is a network for independent mobility by foot or bike, focussing on the more vulnerable users of the public space. They constructed a pleading call for improving the public space with regard to elderly pedestrians and state that the direct outdoor environment, is crucial for elderly to live independent and stay healthy. Weak sub-groups are often overlooked in the design process and the local governments often forget the importance of street design for the elderly. MENSenSTRAAT states that this needs more attention. [31]

1.2.2. The forgotten pedestrian in research

Next to the forgotten pedestrian in policy, also little studies can be found on walking behaviour and pedestrians in general [47]. A limited number of studies can be found that look specifically at older people's use of the outdoor home environment, how they use it and what problems there are. [33, 41] Even less studies focus on elderly walking with a rollator outdoors. [41, 39, 33] Most studies about elderly, mobility and rollators focus on the interior conditions and accessibility indoors of public buildings, and residences. [14, 38, 46] The outdoor environment is significantly important to elderly, but despite this, little research has been conducted on this topic. [41] In addition, little knowledge exists about the factors influencing walking behaviour of elderly. What do elderly perceive as being unpleasant? Moreover, known factors do not always find an integrated place in policy, design and maintenance plans. Let alone, hardly any research can be found that focusses on methods to quantify or map possible problematic factors.

1.2.3. The forgotten pedestrian in data

Because there is no research on pedestrians there is also no data [38]. The PQN report gives several reasons for this lack of data:

1. Pedestrians are low on the transport agenda. Lack of sensitivity and political will on collecting data on walking. No counting means no data, no data means no counting.

2. Data that is collected is fragmented and inconsistent. There is a lack of common standards.

3. Indicators and methods for measuring transport are not appropriate for walking.

4. Existing information is not edited for use.

5. Existence of data is not known or hard to access.

Another remark to make is that walking to other forms of transport, multi-modal walking, is almost as extensive as walking from door to door but is often not included in statistics.Therefore, the numbers are often underestimated in the interest of walking when looking at mobility statistics. [45, 38]

As long as the pedestrian is missing in the data, there can be no research and no actions taken to improve policy. While people that have mobility problems, are struck hardest by obstacles in the public space. [43]

1.2.4. GIS opportunities

GIS technologies and databases can provide great potential for studying the environment and neighbourhood characteristics that influences outdoor walkability quality among older people [47] and by doing so, fill a bit of the knowledge gap for decentralized governments and urban planners. While the role of geo-data in urban design is recognised nowadays, [30] mapping the environment and the problems with GIS gives more understanding and customized information about the city to its city planners in order to develop new interventions and enhance walkability for rollator users. [30, 42] GIS is a strong medium to provide urban planners with the data needed to make the urban area friendlier to rollator users and make cost-effective prioritized interventions. It is a rather easy approach to enhance the knowledge about the urban environment, and to locate certain obstacles and flaws that affect accessibility for the impaired citizens. [42] Here we will look at the opportunities that available geo-data in the Netherlands and analysis provides to fill some of the knowledge gaps and make the obstacles for elderly pedestrians more visible. It helps to show that the build environment is often distorted and hostile for the mobile impaired. [30]

1.2.5. Lack of detail in (geo) data

The scarce amount of studies about the elderly pedestrian, stated that more accurate, detailed and up to date data is needed to map walkability indicators for elderly, then the current and accessible geo-data can provide. [46, 28] Such detailed data is needed, because every stone counts in regard to frail elderly. [30, 28] Importance of small details in relation to the larger infrastructure seems needed to map the walking restrictions in the outdoor activity space of elderly with a rollator [41, 39]. Will GIS be able to map sufficient detail needed for the critical walkability indicators for elderly with a rollator?

1.3. Objective & Research Questions

The overall goal of this research is to create awareness of the forgotten pedestrian in policy, research and data. Awareness may trigger possible action at decentralized governments to increase walkability quality and so increase walking activity of elderly people. To keep them fit and healthy, capable to live independently and grow old in their own house and environment. All contributing to less need for healthcare for the growing share of elder population and reduce the cost of elder care.

The specific objective of this research is to analyse and visualize geodata to explore the critical walkability factors for elderly depended on a rollator in the urban outdoor space. The case study is set in Amsterdam, the Netherlands. To achieve this objective, the following research questions will be answered:

1. What are the critical walkability factors hindering elderly with a rollator in the outdoor environment?

2. Which existing geodata can be used to map and analyse these critical walkability factors?

3. What geodata can be collected with a smart walker to map and analyse these critical walkability factors?

4. How can the available and measured geodata be compared?

1.4. Report Structure

This report exists of 5 chapters, including this introduction chapter. Figure 1.4 illustrates the structure of this report. Chapter 2 describes some background concepts and projects related to this one, which are the inspiration and reference to support this study. Chapter 3 sketches the research area and continues to provide information, per research question, on data, preprocessing and methodology. The final chapter presents the conclusion, the discussion and gives recommendations for future work. Each chapter in this report opens with a short outline of its content.

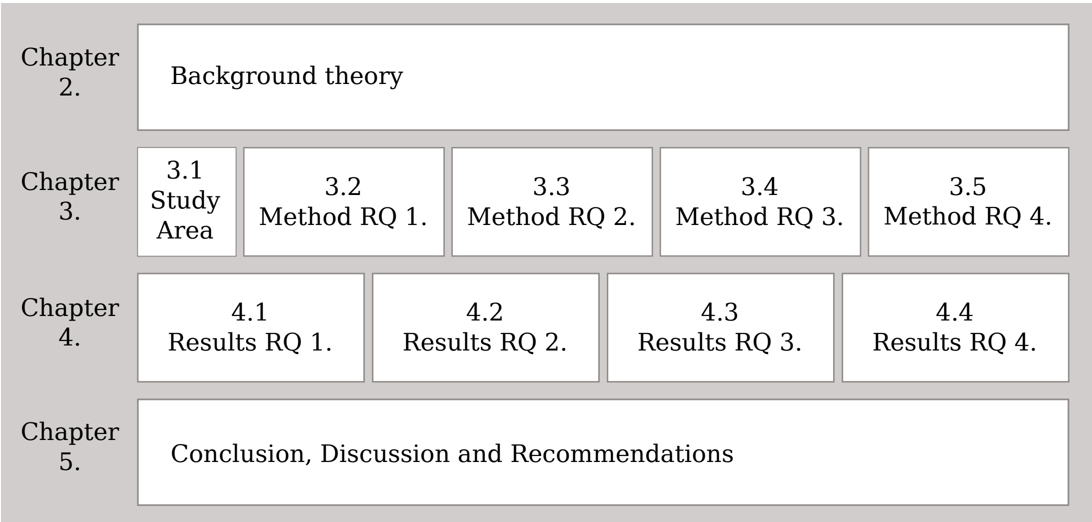

Figure 1.4.: Report Structure

2. Background theory and concepts

In sections 2.1 and 2.2 concepts used in this research will be clarified to have unambiguous use of terms. Section 2.3introduces the Puccini method which is used for the design of the public space in Amsterdam. This chapter will be finished with summaries of related literature which helped forming this research and provide reference and support for the data and methods used.

2.1. Pedestrians

A pedestrian is a person, by foot, with or without helping aids, that moves in the public space. The person is not a driver but a road user. Also persons with a wheelchair, rollator, roller-blades, skateboard or children's bicycle, as well as persons walking with a bike, scooter or motorbike in the hand are pedestrian according to the Wegenverkeerswet voetganger. [14]

Mobility is the freedom to choose to travel and sojourn in the public space, being able to make the trip, regardless its distance. Pedestrian mobility differs from other modes of transport, for it almost part of all other trips. [38]

Sojourning is an important indicator for quality of public space, it includes activities as; recreational walking, waiting and residing in the public space. [38]

The Netherlands is climatic and geomorphological very favourable for walking. [38] In cities almost all streets have two sided side-walks. [38] Though, cycling is perceived much more important in the Netherlands as seen in the pecking order in traffic: public transport, car traffic, scooter, bicycle, pedestrian. In some regions of the Netherlands the soil is rather soft and peaty, in these circumstances the pavement has to be renewed every few years, to prevent sinking.

2.2. Walking behaviour

The rate of walking for a person is determined by many factors, environmental influences, personal influences or behaviour and biological influences. Here we focus on the environmental influences, in specific, walkability of the environment. Walkability is one of the many important determinants that influence the walking behaviour of elderly [47] therefore we try to sketch an overall overview of the walking outdoor determinants. We will base this on the Intervention Mapping (IM) protocol for systematic theory-and evidence-based planning for behaviour change developed by Bartolomew. [7] Because this iterative path starts with the problem identification in order to go to problem solving. It also helps to show where walkability is positioned, next to terms like accessibility and mobility. Figure 2.1 presents the personal and environmental determinants that influence the outcome for walking behaviour of elderly.

The blue square shows walkability as part of the environmental determinants. Our desired behaviour outcome is to increase the choice of walking, consequently increasing health and quality of life. Terms used in dedicated studies are accessibility, walkability, safety and activity space. [47] Accessibility is the ability to access needed facilities and enable persons with disabilities to gain access through for example elevators, audio signals, walkway contours etc. As stated in the previous section, mobility is the freedom to travel in the public space. Here we assume that all elderly have the freedom to go outside, make use of the public space and access the facilities they need. The quality of these routes, the friendliness and the safety are gathered in the walkability determinant. So while a person in walking and accessing the public space, how user friendly and how much effort does it cost to cover these routes?

Some important personal determinants are personal health, previous experiences and perceived self-efficiency. Personal determinants are are often influenced by the environmental determinants, the blue dotted line, but are not part of this study.

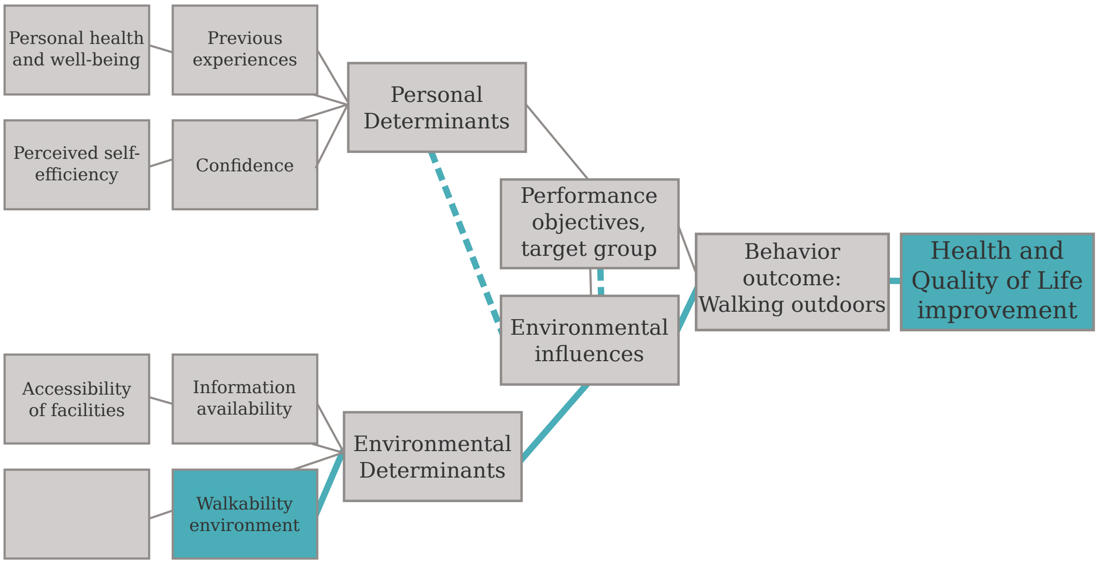

Figure 2.1.: Walking Behaviour Scheme (Source: Boeijen, based on Bartholomew 2011)

The individual path selection criteria of Golledge can be placed next to figure 2.1 to show how they influence the actual choice for walking and that the combination of personal and environmental determinants together make an individual decide to go by foot or not. When choosing a route and having experiences on these routes influence the choice for the next time the user wants to walk that route and which path will be followed. [22] The individual path selection criteria by Golledge knows 3 phases [22]:

1. Choosing destinations

2. Making a route

3. Implementing and feedback. Confirmation or change?

The first two phases are influenced by the many determinants, while the last phase provides new knowledge and experience again influencing the next time a user wants to walk outside. Increasing or decreasing the influence of the previous determinants.

2.3. Puccini Method

Amsterdam is a cultural historic city, with many urban designs from different time periods. The historical city centre, the 19th century canal-belt, the 20-40ties en the postwar city. The urban design has to suit the cultural historic character of the city. For every urban style zones there are material lists and standard design details. [4] A map of Amsterdam indicating where each urban time zone is located can be found in annex A.3.

The Puccini Method is the Amsterdam tradition for the design of the public space in Amsterdam formulating design principles. Public space includes all non-build-up space, open to and accessible by people. The Puccini Method contains all points of policy, from the detailed design to technical details and material lists. It contains four modules, red for streets, green for vegetation, blue for water and water banks, and last, purple for street furniture, street lights and public transport stops. The Puccini method is the handbook for the municipality to maintain and design the public space, it is not an obligatory policy design book. [4]

The Puccini method contains 6 convictions for the design of the public space : [4]

1. **Choose, not share** The streets are used more intensive and pressure increases. Often the usage pressure is higher then the available physical area. Therefore the available space has to be assigned to one use, not shared.

2. **Simplicity and obviousness** The pbulic space should be user-friendly, sustainable, strong in simplicity, timeless and obvious. With simple material and simple design, reaching for good quality.

3. **Craft and skill as a basis** Craft expertise is the basis. Not only designing inside, but going out on the streets with work experience is the key.

4. **Crucial eye for detail** Detail for material use, time, financial resources and facing problems that have to be solved.

5. **A good plan is maintainable** After the realization of a street or square it still has to be maintained. The plan has to take the maintenance into account for the future.

6. **Cooperation** A lot of specialised disciplines are concerned. Throughout the whole process it is important to communicate until the end product is realized.

2.4. Walkability factors from literature

From several literature studies dedicated to pedestrian-ism, elderly pedestrians, mobile impaired pedestrians, rollator users, walkability studies and walking behaviour, a list of possible walkability criteria for elderly with a rollator is created [9, 46, 17, 50, 10, 36, 47, 30, 23, 1, 51, 41, 39]. The focus is on the criteria that are influenced by a wide variety of factors in the urban environment. Factors in the urban environment can be tangible and physical or intangible and more related to personal perception and feelings. [46]

The rollator is a Swedish invention. The Swedish researcher Stäl focusses a lot on research of elderly pedestrians with rollators, on their accessibility and their safety in the public space and how interventions in the public space impact the elderly pedestrian. Stähl is one of the few that looks specifically at the elders perception of the built environment and how specific interventions can help rollator walks be perceived more attractive. [41, 39] An important part in her research, is user involvement, which leads to research with greater relevance and improvements to outdoor pedestrian environments based on the problems identified by elderly people. Stäl claims to be among the very few examples of user involvement in research targeting at societal panning. A mixed-method approach is used emphasising involvement of elderly people, not only as sources of data but also as partners. [41] Conclusions from the studies are that different individual background variables influence older peoples' perceptions of the walkability factors. Perceptions on the outdoor environment are influenced by sexes, functional limitations, use of mobility devices and age. For example, physical barriers in the outdoor environment become increasingly evident with increasing age, among older people with functional limitations and user of mobility devices. [39, 51]

Several other studies, not necessarily aiming at elderly with an rollator or user involvement, made an overview of walkability criteria for pedestrians, elderly or the mobile impaired. Verschuur [46] provides a list of parameters affecting route attractiveness and the studies in which its found, for elderly pedestrians. Duncan (2011) [18] provides a whole list of walkability indicators used for calculating a WalkScore for the general pedestrian. Rosenberg [36] provides a summary of barriers and facilitators in the built environment for mid-life and older adults with mobility disabilities. Wennberg studies a whole list of usability factors and their statistical significance, divided into categories, physical barriers, orientation and warnings, bus stops and shops, orderliness and benches and stairs, for elderly pedestrians [51]. All these lists and other studies are used to create an own overview in order to filter out the most important walkability criteria for elderly with a rollator. This list can be found in Annex A.2

In order to analyse which level in the urban environment is the most important to focus on, all the criteria are made more orderly, by sub-diving them into tree levels of where they could occur.

1. Pavement level
2. Street level
3. Environmental level

Additional, weather related and temporal issues can occur over all these tree levels. Also crossings form a own special niche in the levels for it is not part of the pavement or the street. Therefore,these levels are added to the three levels mentioned above.

1. Weather or temporal level
2. Crossings

In addition, the factors are assigned to different categories focussing on their characteristics such as accessibility or quality of the environment. Five categories can be distinguished. These are inspired by [6] and [36].

1. Accessibility
2. Quality

3. Obstructions or barriers

4. Route attractiveness

5. The feeling of safety

The category accessibility describes the access and presence of pavements. Some examples of factors are: the availability of public transport nodes, availability of bridges, availability of ramps to the pavement a.o. The quality is about when a pavement or stair is present, what the quality is. This could include things as a non slippery pavements, the slope of bridges and the slope of the pavement. Obstruction contains tangible objects that are in the way, temporary or stationary. Like protruding portals and facades, blocking commercial signs or green maintenances so branches are not hanging over the pavement. Route attractiveness is more about the feeling one has towards the routes, the attractiveness can go down with the presence of dog droppings on the pavement, litter and garbage on the streets. While it can go up with the availability of resting benches, public toilets, green and trees along the route. The feeling of safety includes factors as enough time to cross the street, good overview while crossing a street, vehicle-pedestrian interaction, speed limits, presence of street lights, the amount of criminality and many others.

2.5. Related literature for methodology

Literature that discusses the possible methodologies to make walkability quantifiable are rare. Matthews et al. (2011) developed a model for mapping accessibility for wheelchair users and comes closest to this study. Svensson (2010), researched accessibility in particular. Finally, Walkscore from Duncan et al.(2011) is a project focussing on mapping neighbourhood walkability to enhance physical activity among children, adolescents and adults. It provides an interesting method for mapping several walkability indicators. The term Smart Walker is used when referring to measurements with sensors on a rollator in order to increase the capabilities of the rollator. The studies from Wang et al.(2015) and Weiss et al.(2014) focus on the technical aspect of measuring rollator movements and gait characteristics with an accelerometer. The next sections, will give a more detailed summary of the above named articles.

2.5.1. Mapping walkability

A wheeled walker and wheelchairs have a lot in common. Therefore, also literature studies aimed specific at wheelchairs can provide useful insights for rollator research. Matthews et al. 2003 uses a GIS based system to show that the built environment is often distorted and forms a hostile space for wheelchair users. [30] MAGUS, modelling Access with GIS inUban Systems, is a multi-criteria assessment model using quantitative and qualitative techniques to provide urban planners and disabled people with up-to-date, detailed and customized information. This can help the elderly to plan and manage access and mobility in urban areas. At the same time, this provides planners a system that help them evaluate the effects of their design decisions on the mobile disabled pedestrians. [30] The model is based on real-world perceptions, experiences and needs of disabled people. The eventual choices included in the model area, show all possible routes, avoiding bad surfaces, avoiding slopes with a gradient of more then 4% and using only controlled crossings. A drawback in the data was that no information is held on pavement centrelines which forms the starting layer within a GIS model. The solution was manual plotting, and taking into account building outlines, walls, road edges and other linear and point details. So a precise pedestrian route can be mapped. The MAGUS project has been installed at various places in the UK, the report states new fund were available for the MAGUS model to become web-based. [30] This however was in 2001. Recent developments on the MAGUS project are unknown.

Svensson (2010) [42] uses a GIS-model to map and measure accessibility of the urban environment for citizens whit impairments. In order to improve accessibility planners require knowledge about the location of obstacles and how these affect accessibility. Data on the physical environment of different Swedish towns has been collected in order to identify neighbourhood specific characteristics. A digital model of the town's pedestrian network contains information about: slope. height of kerb stones, type of pavement, width of a side walk. They found that only a fraction of the population is able to reach a bus stop from their home, if they are allowed to use only those parts of the pedestrian network that are defined as usable, for mobile and vision impaired citizens. Also the study shows that accessibility varies with different neighbourhood types. [42] Overall the study demonstrates that a GIS system could be used to gain vital information about the need for improvement in the built environment. Rather easily, the knowledge about the urban environment enhances how certain obstacles and flaws affect accessibility for the impaired citizens. [42]

WalkScore presents an web-based geospatial technology to estimate neighbourhood walkability in an interesting way, a weighted multi-criteria method, which could be used as inspiration to extent such methods to a more detailed survey for the mobile impaired pedestrian. It is developed for assessing neighbourhood walkability by Duncan et al.(2011) [18]. The WalkScore algorithm is based on GIS indicators of neighbourhood walkability and ranges between a score of 0-100. It is developed for a large area in four US metropolitan areas with several street network buffer distances, 400, 800 and 1600m buffers. Duncan et al. does not focus on the mobile impaired but at improving physical activity among children, adolescents and adults.

2.5.2. The Smart Walker

There are a few researches on making a rollator more smart by using sensors; the Smart Walker. Most of these studies focus on fall protection, early warning systems or indoor navigation. There are functions such as sensor assistance, health monitoring, navigation help or cognitive assistance, obstacle avoidance and fall detection. [48] Most studies using an accelerometer as a sensor, calculate gait parameters such as; step length, gait cycle, step width and gait variability. [48] Often these studies are done in laboratory settings, using high quality sensors and sensors attached to the body. Our own research aims at obstacle detection, with the help from detecting the movement of the rollator. At this moment in time conducting this research, no research of this kind had been published.

Weiss et al. (2014) uses a smart walker to detect walking behaviour change in real time with an accelerometer mounted on the rollator. [49] No sensor on the user is needed, but the walking behaviour is detected based on the motion transfer by the user on the walker. The goal is to identify five different classes: no movement, movement, slow, normal and fast. They confirm that walking behaviour changes can be detected by using a 3-axis accelerometer sensor on the walker. [49]

Wang et al. (2015) uses a standard 4-wheel rollator with a defined walking frame, where the accelerometer is positioned in the middle point between the two rear wheels. By doing this the exact distances to the wheels are know and from this the position change of the walker can

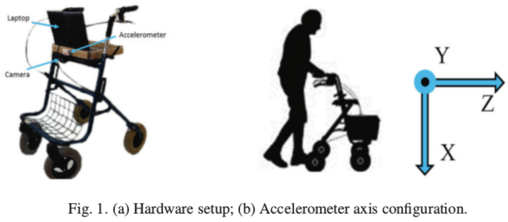

Figure 2.2.: Rollator with accelerometer axis configuration. From Weiss et al. [49]

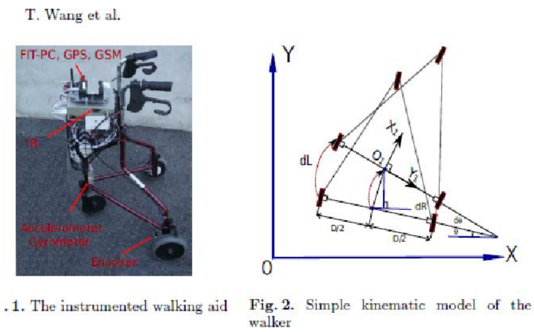

Figure 2.3.: Rollator research set-up. From Wang et al. [48]

be determined. By using a high cost motion capture system, the calculated trajectory's and the gait or step detection, are validated. Wang was able to calculate the displacement of the walker during every step with an accuracy of approx 1 cm. [48] By comparing a group of young adults with group of elderly people, Wang found the the walking accuracy of the elderly is lower but that step length, step period and walking speed between the two groups has no obvious difference. The classical gait indicators are not sufficient or sensitive enough to evaluate the fall risk of elderly. [48]

2.5.3. Concluding

The MAGUS model of Matthews and the Walkscore from Duncan, both use a multi-criteria model. MAGUS including criteria as avoiding slopes, cobbled pavement surfaces and using controlled crossings as input. Walkscore, was more general, and focussed more on accessibility, using network length and network nodes density. Svensson focussed more on comparing different neighbourhood designs and collected data on slope, height of kerb stones, type of pavement and width of a side walk. Both Wang and Weiss made use of a non-intrusive measurement method, were no devices where placed on the participants but only on the rollator. In order to measure gait characteristics and walking behaviour.

For this study both methodologies will be combined. First, the walkability factors are mapped using existing geo-data. Second, the concept of a Smart Walker with an accelerometer will be used to map more in detail the effects of obstacles in the build environment on the walking behaviour and movement characteristics of the rollator.

3. Data and Methods

This chapter starts with a small section on the research area 3.1. Then, per research question a section is dedicated, describing its data, pre-preprocessing steps and the analysis. In section 3.2 the methodology for literature studies and interviews is explained to find critical walkability factors (research question 1). Section 3.3 shows the data collection and pre-processing steps for the analysis of existing geo-data, research question 2. In section 3.4 the data collection and pre-processing steps for the collection of our own geo data, with GPS devices and an accelerometer are explained followed by the steps for analysing this data (research question 3). The changepoint methods for comparing the existing geo-data with the own collected data is explained in section 3.5. Changes in the time series of the rollator walks are detected and plotted on the map to compare the data sources (research Question 4).

3.1. Study area

This project in conducted for the project MeetRollator in the scope of the recently founded Amsterdam Institute For Advanced Metropolitan Solutions (AMS). The study area of AMS in Amsterdam, see left figure 3.1 for the location. The Amsterdam Municipality contributed with data that covers the centre area of Amsterdam, indicated with the red square in the right figure 3.1. The literature study, interviews, AHN study will be mostly focussed on this area. The more general measurements were taken in Wageningen due to a more conventional location and travelling circumstances for the conducting researcher. See figure 3.10 from chapter 3.5.

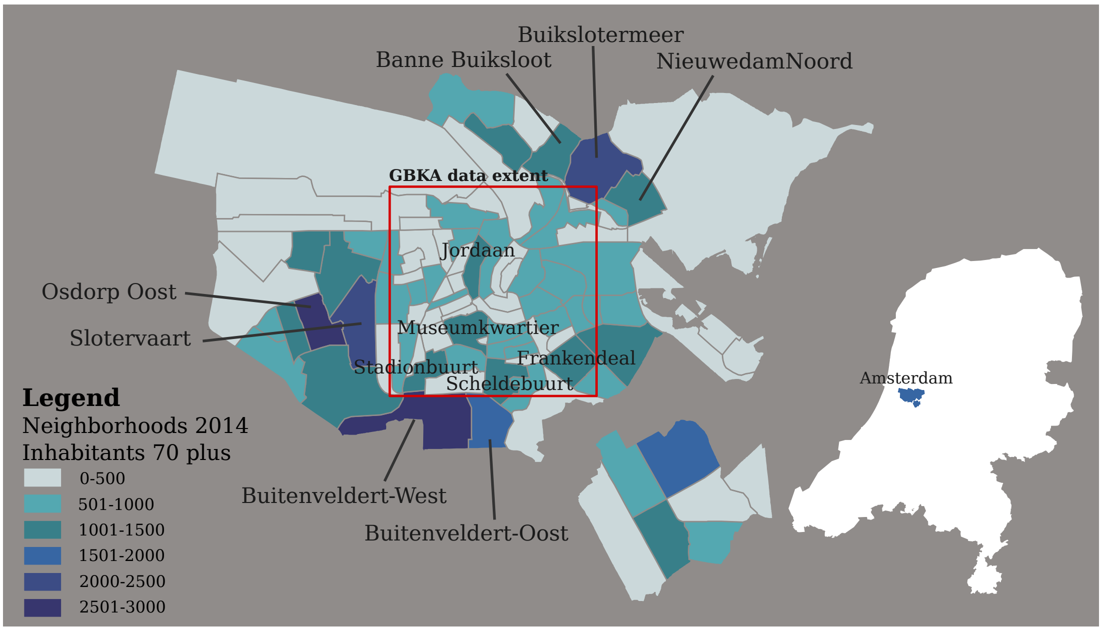

Figure 3.1.: Study area Amsterdam, The Netherlands

There is no exact information on the amount of elderly using a rollator in Amsterdam or where they live. There for the CBS statistics of 2013 were used to detect the neighbourhoods were the most elderly above 70 live. In figure 3.1 can be seen that in the centre the most elderly live in the Jordaan. In the whole of Amsterdam the most elderly can be found in the South West and North.

3.2. Method RQ 1 - Finding the critical factors for walkability

3.2.1. Literature study

From literature research, all possible problems that elderly with a rollator can encounter were gathered. Together with the extend of the problem importance. This to form the first main idea of what the possible critical factors could consist of and the eventual list of findings will be used to support and design the interviews with the elderly and finding requirements in the policy and design policies. The literature study was conducted from October 2014 until January 2015.

3.2.2. Interviews

In the initial idea was an interview that would consist of 3 parts; first a general part, about age, health and the use of the rollator. The second part is a list of possible problems the participant could encounter. The third part would be drawing on a map, where the participant walks and where certain problems occurred. See overview 3.2. Though after developing and experimenting the final form and the method of conducting changed quickly.

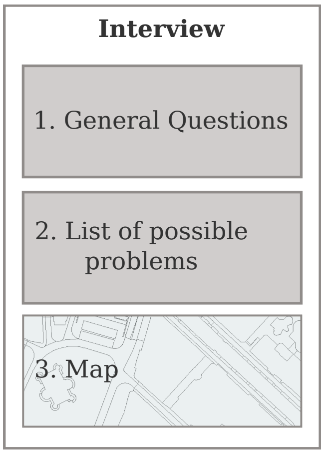

Figure 3.2.: The 3 parts of the interview

The questionnaire as shown in Annex A.4, consisting of several pages was developed. The questionnaire was tested, with the researchers grandparents. This concluded that the questionnaire is not a good form for obtaining information form elderly. The reaction of the participants was, that things were unclear and not all questions were answered. Also the amount of text scared the elderly, feeling uncomfortable with their abilities of reading and writing. Therefore, the form of the interview quickly changed to an informal chat, were the researcher used a check-list, making sure all questions were asked while chatting in random order.

The second part, containing a list of possible problems the elderly could encounter was constructed after the literature research. 5 categories are constructed:

- Quality of the pavement

- Obstacles
- Overall business
- Safety feeling
- Environmental characteristics

The total list can be found in annex A.6. For the elderly did not feel like reading too much, also this part of the questionnaire was conducted orally. Every possible problem on the list, were read out loud to the elderly and asked to rate from 1 to 5, 1 is they never encounter the problem to 5; they always encounter the problem. The conducting researcher circled the number from 1 till 5 according to the story of the participant.

The third part, drawing or pointing out problems on a map was quickly cancelled, as the elderly had difficulties reading the maps. They did, though, name streets and locations but the conducting researcher was too unfamiliar with the surroundings to translate this quickly onto the map.

Several elderly care houses were contacted as well as the neighbourhood care of Amsterdam centre. While sounding enthusiastic from the first point, it was hard to arrange appointments with elderly.

The total amount of participants for personal interviews were only 2.

Next to this, also participants on the Rollator Loop were interviewed. Around 10 people were shortly interviewed about the general problems they encounter while walking outdoors. But not the complete list.

3.3. Method RQ 2 - Collection and analysis of available geodata

Data was available on walking speed, topology of Amsterdam and a height map of the Netherlands. The average walking speed was conducted as input for choices in research question 3 and 4. The topology provided a basic map of the available pedestrian area and the height map gave insight in sloping pavements.

3.3.1. Rollator Loop - Average walking speed

We visited the yearly event, the Rollator loop in Amsterdam on the 9^th of September 2015. Here we conducted interviews, measured several walks and gained overall information about the walking performances of that day.

Little information can be found on the internet about the general walking speed of elderly with a rollator. Because the opportunity was there to find out more about the average walking speed of elderly with a rollator, this was conducted as well. MySports, a company for time tracking during sport events, measured the walking time of every participant. [12] The outcome of the Rollatorloop 2015 and 2014 were used to do a small side study on walking speed per distance and gender.

3.3.2. Data Collection and Pre-processing - Topology

The municipality of Amsterdam, provided the GBKA (grootschalige basis kaart Amsterdam). The GBKA is the precursor of the BGT (basisregistratie grootschalige topografie) which will be used after 1 Jan 2016: the basic registration of large scale topography. The GBKA is obtained, maintained and provided by the municipality. It contains information about transport, water, buildings, street furniture, land use and public space. [3] The GBKA is delivered in file format ESRI Shape files and is projected in RDnew.

Next to this also the website amsterdamopendata.nl is consulted for extra data. [32] The data downloaded form amsterdamopendata are CSV files containing the X and Y coordinates in RDnew and WGS84. The CSV files are opened with Qgis and transformed to Shape file to work with the rest of the data.

3.3.3. Analysis - Determining pedestrian area with GBKA

The detailed GIS study will be done on the area Jordaan in Amsterdam. The Jordaan is part of the Historic Centre belt form the Puccini method. (Gordel Historische kernen) This means most pedestrian pavements and streets are made out of baked red bricks. [4] The GBKA contains polygon features for road sections. Though, these do not contain a label, indicating which purpose of use it has. See [3]. The first step will be to see if it is possible to derive the pedestrian area from available data. The Puccini method contains 6 classes for road destination [4], see the list below. Though this distinction is not used in the geo data available at the municipality.

1. Pedestrian

2. Bicycle

3. Public transport

4. Trees and street furniture

5. Cars (moving)

6. Cars (Parked)

For analysis, this research we are only interested in the pedestrian area, so the distinction between areas to walk on safely, and areas not walked on safely is made. The classes from Puccini are simplified to 3 classes, were mixed space is not taken into consideration.:

1. Transport: Cars, bikes, public transport.

2. Pedestrian area : Including square, stairs, parking places.

3. Unpaved: trees, parks, bank, garden.

First, all the road sections of all levels are merged with the bridge features and clipped to the Jordaan neighbourhood. A new column is created, class, to assign 1,2 or 3 to according to the purpose of use. Figure 3.3 shows the decision tree of steps taken to assign the three classes to the road sections. The classification process starts from the top to the bottom, in every step assigning the selected group the class and continuing with the features which do not have a class assigned yet. The first steps are done by selecting criteria on the available attributes of the road sections. After this other shape-files from the GBKA are used to derive pedestrian area and the tool selection by location is used. For example, street furniture is often placed on the pedestrian area and not on roads for moving cars. In the end, all remaining sections are assigned class 1 transport. All data is from the GBKA except the parking lots which are downloaded from www.amsterdamopendata.nl.

3.3.4. Data Collection and Pre-processing - AHN

The AHN2 tiles covering the research area were downloaded from www.nationaalgeoregister.nl. The AHN is measured with laser altimetry or LIDAR. Laser beams shot from an air plane and localized with GPS. It is measured over several time periods and merged in the end to get a detailed measurement of the height. With a measured point density of 6 to 10 point per m^2 [44]. The eventual end product delivered is corrected to ground level, so vegetation, buildings and other object do not appear. [44] These filtered areas are given no-data values. The raster data has a resolution of $0.5m^2$ and a precision of systematic and stochastic error of max $5cm$. The projection is the Dutch projected coordinate system RD new. [44] Because the AHN2 is already delivered in RD new and corrected for ground level, no or little pre-processing is needed. Apart from downloading the correct tiles and merging these together for the appropriate area.

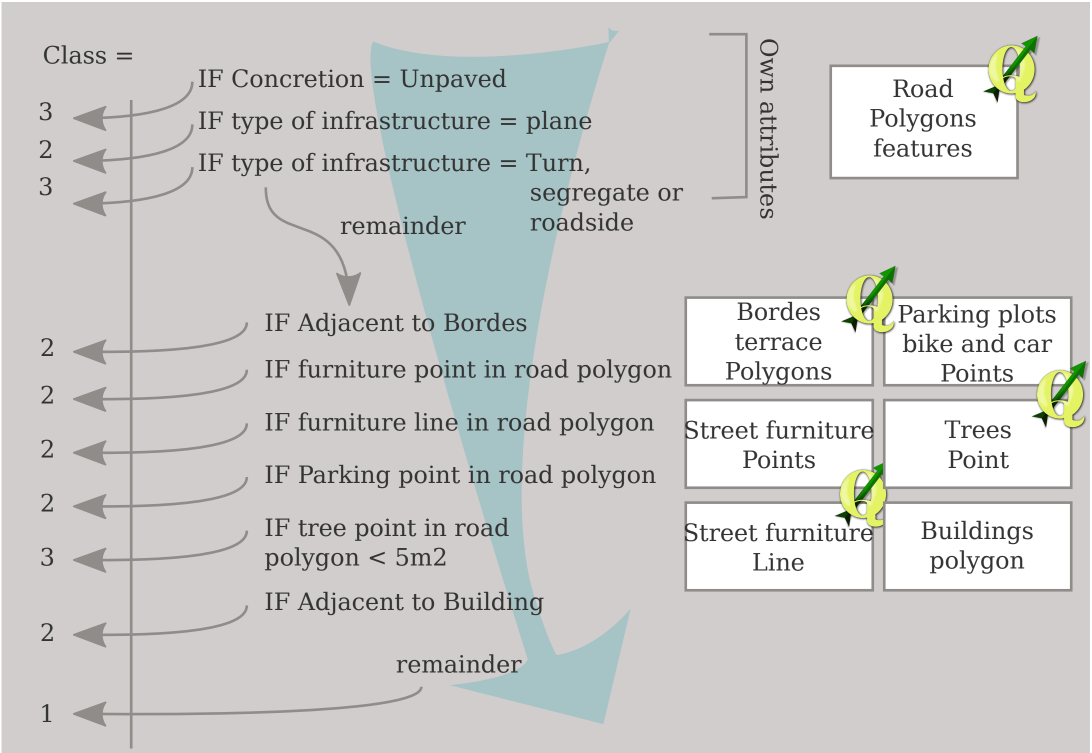

Figure 3.3.: Classification steps road sections

3.3.5. Analysis - Mapping sloping surfaces with AHN data

The Policy of Amsterdam states that pedestrian areas with slopes more than 4% is perceived negative. [40] The slope is derived from the AHN2. Also per road section, the average slope is calculated. The pedestrian classification with the GBKA are used to compare road sections for transport versus pedestrian area.

First derivative - Slope

The first derivative or slope provides the degree of slope per pixel. This can be calculated with the following formula on cell to cell basis.

Degree of slope:

$$\tan\theta = \frac{rise}{run} \tag{3.1}$$

[20]

So slope in degrees:

$$\theta = \tanh \frac{\sqrt{\frac{dz}{dx}^2 + \frac{dz}{dy}^2} * 180}{\pi} \tag{3.2}$$

Source: ESRI http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=How%20Slope%20works [20]

3.4. Method RQ 3 - Collection geodata of rollator movements and analysis

The data collection and pre-processing per sensor used in this research will be explained in the next sections per sensor. The different sensors make use of different time zones or geographic systems, therefore some general pre-processing steps had to be conducted to standardize all the files in order to compare them in the end.

3.4.1. Data Collection - GPS

Several sensors were used for measuring GPS, varying in its details and specifications. The reason several ways to measure location were used is because not all the devices were available all the time.

Garmin Summit For the rollator loop the Garmin Summit was used with the following specifications:

- Time zone: UTM
- Projected Coordinate System: WGS84

GPS Geotracker On the smart phone the application GPS Geotracker was used. Version: 3.0.3 from 23 July 2015 Author: Ilya Bogdanovisch. This resulted in the following specifications:

- Time zone: UTM
- Projected Coordinate System: WGS84

Leica GNSS RTK For more precise location measurements the Leica system was attached to the Measurement Rollator. Though, only one Leica system was available and it was to heavy to attach to an elderly's rollator. The following specifications:

- Time zone: UTM
- Projected Coordinate System: WGS84

The Leica is much more precise then the Garmin or the GPS tracker on the smart phone. But when the Leica was not available, the other two methods still gave a good reference as were the route was.

3.4.2. Data Pre-processing - GPS

Figure 3.4 shows all pre-processing steps that are applied to all location datasets. First the files are imported into Arc-map, creating point features. From from GPX or KLM file. When necessary, they were transformed from WGS1984 to RD new. The time attribute was edited all data contained the format YYYY-mm-dd HH:MM:SS.OOO and was transformed to time zone CET. The Track Analyst tool was used for computing difference in time, speed and course between every GPS point. The settings used are:

- First to second point
- Meters, Seconds, Meter per seconds and Degrees

Eventually, the dataset were manually edited to delete the start and end points, if necessary. To exclude the waiting time before the actual walking, and the waiting at the end to turn the devices off.

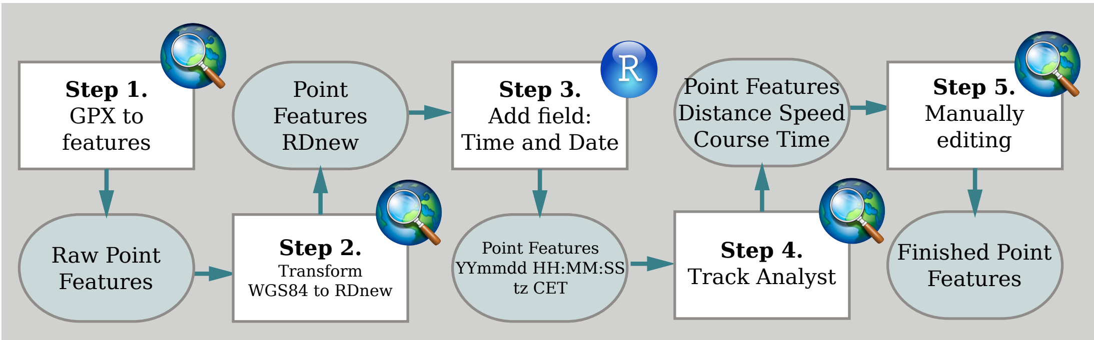

Figure 3.4.: GPS pre-processing flowchart

3.4.3. Data Collection - Accelerometer

We used a Samsung Galaxy Core GT-I8260 smart phone which was available at the conducting faculty. With the application; Accelerometer Physics toolbox accelerometer to extract the 3-axis acceleration data on the X, Y and Z axis and the total acceleration called g-force. Physics Toolbox Accelerometer proved to be the best option for extracting the data, for it is easy to use, can store the data in a csv file, with current clock time, time stamp and saves it on the local storage of the phone. It does not require a constant internet connection, and was free for use. Also no knowledge on any pre-programming to read the sensors was required. Some of the other application alternatives considered are: Accelerometer Monitor from Mobile Tools, Accelerometer Monitor from Keuwlsoft Tools, and the AcMeter. Their specifications and reasons why not used, can be found in Annex A.5.

During all measurements, the smart phone will always be placed horizontally on the Rollator. This means the z-axis is pointing down, and will correlate most with movements up and down. The x-axis will be pointing sideways and the y-axis front and back. Acceleration of walking speed will be seen in the y-axis. While turns will be seen in the x-axis. See figure 3.5.

Application version change

Several versions of the application were used, as the developer updated the app meanwhile. [1] In September 2015 version 1.2.9 was active. On September 9th the version available was

[1] Information provided by Chrystian Vieyra, developer of the Physics Toolbox Applications. In e-mail conversation 26-10-15.

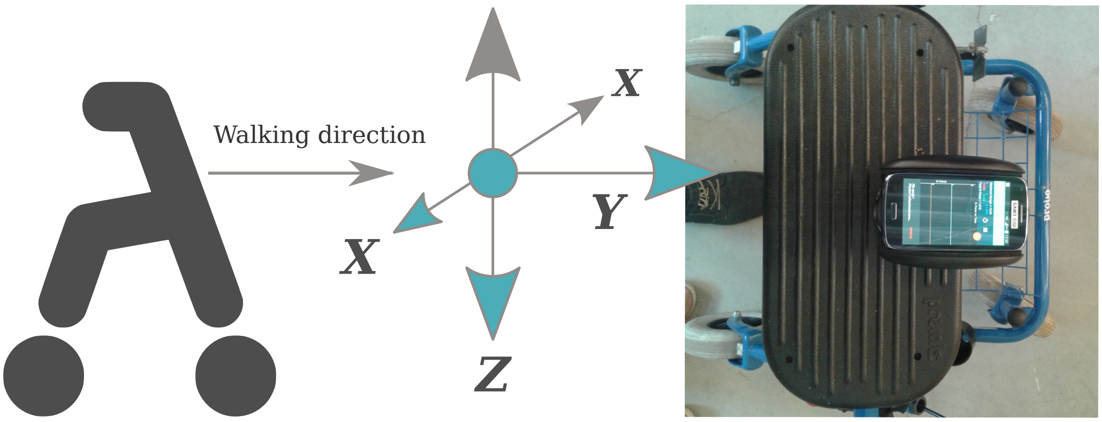

Figure 3.5.: Graphical representation of the direction of the axis of the accelerometer on the rollator.

1.3.6. Though, the smart phones used, were not always attached to the internet, and so version 1.29. was used in the beginning. This resulted into failed experiments for there was no wake lock, which keeps the device awake even if the screen turns off while the record button has been pressed. So the app was put to sleep during the measurements. Test rides on a bike were conducted but the gaps of missing data seemed to happen when large bumps occurred in the road and the conducting researcher kept the screen awake more often by touching the smart-phone more often.

Later measurements were taken with version 1.3.6 and 1.3.7, which did continue the app measuring when the screen was in sleep mode. The only difference between version 1.3.6 and 1.3.7 is a spelling mistake and the graphic layout of the record button.

3.4.4. Data Pre-processing - Accelerometer

The accelerometer dataset contains the following specifications:

- Time zone: CET. Same as the smart phone settings.
- CSV time stamp: clock time in milliseconds
- No location

The measurements resulted in dataset with per feature :

$$F_(i) = [Timestamp, A_x, A_y, A_z, A_m] \tag{3.3}$$

With A_x as the $x - axis$ acceleration A_y as the $y - axis$ acceleration A_z as the $z - axis$ acceleration and A_m as the total acceleration.

The total acceleration or g-force is supplied by the application: It is the total acceleration vector of the 3 axis combined. When tested, the calculated A_m is equal to the g-force provided by the application. It will be referred to as A_m or total acceleration, for G-force can be a confusing concept. It can be calculated by:

$$A_m = \sqrt{{A_x}^2 + {A_y}^2 + {A_z}^2} \quad (3.4)$$

For each time series A_i , with $i = x, y, z$

With cross correlation between the several features, we can detect which feature best represents the walk characteristics. A_m is a representative parameter which includes the gait acceleration (Y-axis), the vertical acceleration (Z-axis) and the lateral acceleration (X-axis). [49] By doing a cross correlation with the Z-axis and the X and Y axis a similarity between the lateral acceleration, mostly caused by the surface, and the gait acceleration is detected. The cross correlation of the x and z axis is expressed by:

$$Corr_{z,x} = \sum z(n)x(n-1) \quad (3.5)$$

Accelerometer output ranged between the normalized range of -2 to 2. Assumed is that the value of 1 means equal to 1 times the gravitational force: 9.81 m/s^2 and the value of 0 means no force pulling, so the sensor is flat. The developer stated, that these normalized values differ per type of smart phone.[2]

The application contained several settings, which were not described in the application nor on-line. Therefore some sample test were conducted to gain some basic information about the application values and settings. The application had four record interval settings, Normal, UI, Game and Fast. By placing the phone for a while on the table with the different settings the following information was found about the sample frequency of these settings:

Table 3.1.: Sample frequency of the different settings.

Setting	Points per sec (exact)	Points per sec (approx.)	Periodicity (1/(points per sec))
NORMAL	4.6	5	0.2
UI	11.9	10	0.1
GAME	49.6	50	0.02
FAST	99.4	100	0.01

This means that with an average walking speed of $1.3m/s$ the distance between the measured points will be, $26cm$ for NORMAL sample frequency, $13cm$ for UI, $2.6cm$ for GAME and $1.3cm$ for FAST sample frequency. For further calculations the setting NORMAL is used. This because an interval of 26 cm seams sufficient and the data set will be not too large in size to handle.

[2]Information provided by Chrystian Vieyra, developer of the Physics Toolbox Applications. In e-mail conversation 26-10-15.

Sensor errors

Because the accelerometer sensor is not calibrated and the quality is unknown, it can contain random errors (caused by the accuracy limit of the measuring instrument) or systemic error (caused by incorrect calibration of the measuring instrument). By placing the smart phone flat on a table, laying still for several hours, an indication can be given of the sensors offset. This means the z-axis is pointing down and also contains one time the gravitational force pulling it down. Resulting in numbers around 1. The x and y axis are pointing to the side and front/back. Being flat and resulting in numbers around 0.

The following sensor errors were found with setting NORMAL for every axis:

Table 3.2.: Average error per axis. Sample frequency 5 per sec (NORMAL)

SAM 3		SAM 4		SAM 5	
Average error from 0		Average error from 0		Average error from 0	
ξ_{A_x}	-0.04	ξ_{A_x}	-0.05	ξ_{A_x}	-0.03
ξ_{A_y}	0.03	ξ_{A_y}	0.06	ξ_{A_y}	0.05
ξ_{A_z}	1.01	ξ_{A_z}	1.02	ξ_{A_z}	1.03
ξ_{A_m}	1.02	ξ_{A_m}	1.02	ξ_{A_m}	1.03

These average errors ξ_{A_x} , ξ_{A_y}, ξ_{A_z} and ξ_{A_m} are extracted from all measured Accelerometer time series per smart phone.

3.4.5. Assigning location to accelerometer data with GPS

For reference, the accelerometer data can be linked to the location by using the time-stamp of the accelerometer and the GPS points. With the time stamp, the first GPS point before and the first GPS point after that time is taken. Because the time difference between the first GPS point and the unknown accelerometer point is known and the speed (s) between the GPS points, the distance(d) and so location(x, y) of the unknown accelerometer point is calculated.

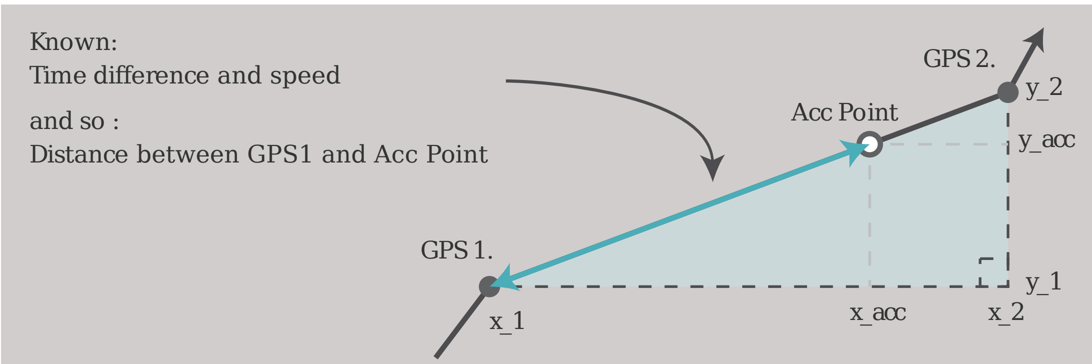

Figure 3.6.: Graphical explanation of changepoint location calculations

With coordinates (x_1, y_1) and (x_2, y_2) in RDnew as the known first and second GPS point, respectively.

The distance between (x_1, y_1) and (x_2, y_2) is calculated by:

$$d_{1,2} = \sqrt{(}y_1 - y_2)^2 + (x_1 - x_2)^2 \quad (3.6)$$

Then, the distance between GPS point 1 (x_1, y_1) and the un-located accelerometer point (x_{Acc}, y_{Acc}) is calculated with:

$$d_{1,Acc} = s * timedifference((x_1, y_1) - (x_{Acc}, y_{Acc})) \quad (3.7)$$

The unknown x coordinate of the accelerometer point is calculated with:

$$x_{Acc} = x_1 + \frac{d_{1,cp}}{d_{1,2}} * (x_2 - x_1) \quad (3.8)$$

And the unknown y coordinate of the accelerometer point is calculated with:

$$y_{Acc} = y_1 + \frac{d_{1,cp}}{d_{1,2}} * (y_2 - y_1) \quad (3.9)$$

Now we can add the location specific data to the changepoints, the speed(S) extracted from the track GPS points and the AHN values, height and slope. Resulting in a feature per observation of:

$$F_(i) = [Timestamp, A_x, A_y, A_z, A_m, s, height, slope] \quad (3.10)$$

3.4.6. Data Collection - Movie material

Most walks were recorded on film, for reference aid. This was done with either a go-pro, flip camera or with the smart phone camera. Pointed at the direct surface in front of the rollator. The images are not used for calculations, solely for reference backup.

3.4.7. Analysis - Mapping irregular surfaces with an Accelerometer

Several test were conducted with the Measurement Rollator on different surfaces. To see if the vibrations of the rollator are more fierce on surfaces with a more irregular surfaces. Indicating more surface hindrance and so more energy is needed for the rollator user. The assumption is, that the vibrations caused by surface hindrance can be measured through the variance of the z-axis acceleration. We used the Accelerometer (Physics Toolbox version 1.3.7) and the Garmin to record GPS. The goal was to walk with an average walking speed of $4.7km/h(3.26.2km/h)$. This is the walking speed found from literature and own research. Though, while walking it felt quite fast. So the walking speed was kept around 4 km/h as best as possible. The researcher walked herself with the rollator over different surfaces. Each a distance of around $20m$. All the pavement surfaces structures shown in image 3.7 were tested. Asphalt or tarmac, brick paving, tiles, gravel, grass and a smooth concrete surface inside was measured.

Figure 3.7.: Image of every measured surface

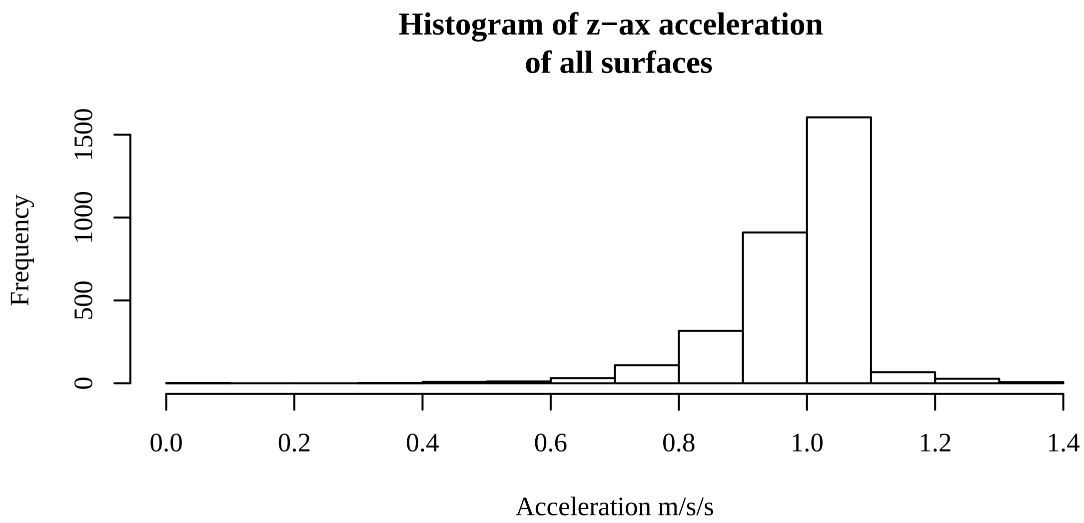

Figure 3.8.: Histogram of all surfaces z-axis acceleration

Statistics

By providing the descriptive statistics of the accelerometer output as a normal distribution, the differences in the vibrations on different surfaces can be explained. The data is approaching a normal distribution as can be seen in the example histogram of all the surfaces combined.(3.8) Vibration goes into both directions so the mean will not show a surface specific outcome and will not differ much between the different surfaces. The means calculated only gave values around the 1. See table 4.5 in the results. The variability shows better how rough the surface is. Therefore the variability is used, or the standard deviation together with the 5-number summary to create box plots. Including, the minimum, maximum, median and first and third quantile. To show a better understanding of the effect of the surface on the vibrations on the rollator. The formula for the mean variance and standard deviation:

Mean:

$$MeanA_z = \frac{\sum_{k=1}^{n} A_z}{n} \tag{3.11}$$

Variance:

$$\sigma^2 = \frac{\sum_{k=1}^{n}(A_z - mean(A_z))^2}{n-1} \tag{3.12}$$

Standard deviation:

$$\sigma = \sqrt{\frac{\sum_{k=1}^{n}(A_z - mean(A_z))^2}{n-1}} \tag{3.13}$$

Comparison with Matthews et al. (2003)

In Matthews et al. (2003) [30] a reference score for hindrance of specific surfaces is provided. Shown in table 3.3. Small test were conducted measuring surface hindrance for wheelchair users, aiming at surface type and quality for mobility. Six common urban surfaces were tested: concrete, paving, tarmac, brick, grass and gravel. A wheelchair with occupant was pushed down a small ramp the distance rolled provides an measure for rolling resistance. [30] These values will be used as a reference, to see if the measured vibrations of the Accelerometer correlate. Because the reference numbers are relative, also the measured outcome is recalculated to a relative factor. Taking the most smooth surface as factor 1 and calculating the rest of the surfaces from this. See results in figure 4.7 for a comparison of the values of Matthews and the calculated factors.

Table 3.3.: Relative hindrance scores of surfaces, low scores represent levels of least hindrance [30]

Concrete	Paving	Tarmac	Brick	Grass	Gravel
1	1.2	1.3	1.6	6	8

3.5. Method RQ 4s - Mapping abnormal or change events with changepoint detection using Accelerometer, GPS and AHN2 data

Assuming that in the optimal circumstances, someone will walk with a specific speed in a monotonous way and the pavement has a regular surface, the measured acceleration in the z-axis will show a monotonous pattern. An *abnormal* peak in the continuous data will indicate a problem or obstacle in the pavement surface. Next to this, a sudden change in the walking speed of the person, could indicate a disturbance of the walking route. Together, a sudden drop in speed, plus a peak in the z-axis acceleration, could indicate big bumb or obstacle which causes a change in the walking behaviour of the pedestrian. For example, tackling a curb obstacle with the rollator.

By looking at the changes or anomalies in the time series data of speed, slope and z-axis acceleration measured during a walk and linking them to location trough GPS measurements, the physical obstacles or hindrances can be located. The changes or anomalies in time-serie data can be determined by the change-point package of R containing specialized change-point finding algorithms for detecting multiple change-points within data and a variety of test statistics. [26, 25] A changepoint is the estimation of the point at which the statistical properties(mean or variance) of a sequence of observations changes.

3.5.1. The changepoint package

The ChangePoint package of Killick et al. 2014 contains functions to detect multiple changes in the mean or the variance of large datasets. First we will explain the concept of change-points and the segment in between. Then, the methods offered by the package will be explained and the possibility to choose different statistical models for penalty fitting. The exact approach of identifying multiple change-points, formulas, methods and references can be found in the report of the changepoint package by Killick et al. 2014 [25]

Having an ordered sequence of data $y_{1:n} = (y_1, ..., y_n)$, a change-point is said to occur within this set when there exists a time, $1, ..., n1$, such that the statistical properties of segment $y_1, ..., y$ and segment $y_{+1}, ..., y_n$ are different in some way. Consequently the m change-points will split the data into $m + 1$ segments, with the i^th segment containing data $y_{(_{i1}+1):_i}$. Each segment will be summarized by a set of parameters. [25] Possible is to use the two sides: the change-points $CP_{1:m} = (CP_1, ..., CP_m)$ themselves and the segments $y_{(CP_{i1}+1):CP_i}$ between the change-points. Each, with its own set of parameters. The average variance or mean of the segment indicates the homogeneous characteristics of the dataset, between the change-points.

The Changepoint package implements three multiple change-point algorithms; Binary Segmentation(BS), Segment Neighbourhoods(SN) and the Pruned Exact Linear Time(PELT). Binary Segmentation is an approximate algorithm and most widely used search method. Segment Neighbourhoods has a long computation time but is more exact. PELT is computationally fast and exact. The number of change-points increases linearly as the data set increases. In addition the package provides a variety of test statistics for the penalty type settings, for example: BIC, AIC or Hanan-Quinn. The penalty settings are used to prevent the model for over fitting and increases the number of parameters in the model to almost always improve the goodness of fit. The default is using no model and taking all measurements into account. When using Asymptotic penalty, the theoretical type I error (0.05) is used. Also a manual penalty can be set, this can be a numeric value or text giving the formula to use. Available variables are n=length of original data. [25]

All the different changepoint detection methods had to be tested to see which model approaches the most plausible result and approaches the truth the best. This was shortly done for all individual dataset. Also the best possible penalty settings are considered when there was over or under fitting. We found big difference in characteristics of the dataset for speed, slope and acceleration. Most often the penalty was set manually to $1.5 * log(n)$ to ignore extreme measurements.

3.5.2. Routes measured

For testing if the change-point method is usable for detecting obstacles while walking, several test were walked, during the RollatorLoop 2015. We used the Garmin Summit for the participants and the Leica system on the Meetrollator. 3 smart phones with the Accelerometer (Physics Toolbox version 1.2.9 were used. Here all the accelerometer measurements failed because or the wrong application version. See Annex A.7 for the measured tracks and the accelerometer output. Eventually, the failed measurement with the Leica system, could be used for analysing speed and slope. But the accelerometer was left out here. Also, half way the route, the Leica system stopped walking. Therefor only half of the route was measured. See figure3.9 for the route. So, secondly a bike ride was monitored for testing the application settings again, with the Accelerometer (Physics Toolbox version 1.3.7) and the GPS Geotracker Application to record GPS. When this seemed to work, also a walk with the measurement rollator was conducted by the researcher herself. Using the Accelerometer (Physics Toolbox version 1.3.7) and the Garmin Summit. Both tracks are shown in figure 3.10.

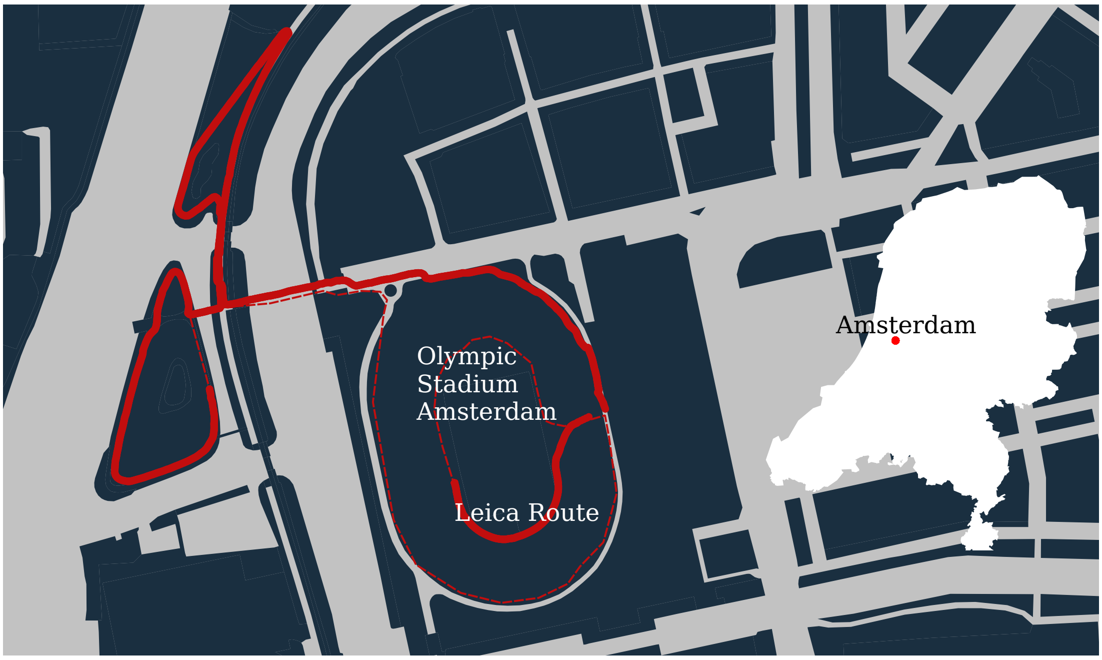

Figure 3.9.: Map of Leica route in Amsterdam

The datasets of the accelerometer are combined with the location dataset of the GPS measurements. The location assigning is done with the same method as described in the previous section

3.4.5. Also here the location specific data was added to the dataset, the speed(S) extracted from the track GPS points and the AHN values, height and slope. Resulting in a feature per observation of:

$$F_(i) = [Timestamp, A_x, A_y, A_z, A_m, s, height, slope] \quad (3.14)$$

The dataset per route was approached as a time-series dataset to applying the changepoint method. Each route and data range on the route had its own specific settings to get the best model of fit. Eventually this resulted in a changepoint feature for every $m^(th)$ changepoint observation:

$$CP_m = [breakpointindex, mean, variance, time, x, y] \quad (3.15)$$

This is applicable to the acceleration, speed, slope and height. The change-points are detected with the variance setting for the acceleration and mean for change-points detection for speed, height and slope:

$CP_{mean(s)}, CP_{Var(A_z)}, CP_{Var(A_m)}$ and $CP_{meanHeight}, CP_{meanslope}$

With all change-points having location coordinates(x, y) in RD new and a time stamp. When plotting all changepoints on the map, visually, patterns in the route can be detected.

Figure 3.10.: Map of tracks measured in Wageningen

4. Results

Per research question a section is dedicated, describing the results. The final critical walkability factors are given in section 4.1 The average walking speed of elderly can be found in 4.2.1. Section 4.2 the outcome of the pedestrian area classification and the slope. In section 4.3 the surface signatures and comparison with surfaces from Matthews is presented. The last section 4.4 opens with a change-point method comparison, were after it presents per route a map with the derived change-points.

4.1. Results RQ 1. - Finding the critical factors for walkability

Critical walkability factors are found in literature and several interviews. The final list is presented in section 4.1.5.

4.1.1. Findings critical factors from literature

Table 4.1 shows a summary of the occurrence walkability criteria in literature [9, 46, 17, 50, 10, 36, 47, 30, 23, 1, 51, 41, 39], per category and level. The criteria are counted double if found multiple in different literature pieces. As can be seen in the table, most reports mentioned criteria that can be found on pavement level and criteria falling into the category of route attractiveness.

Table 4.1.: Amount of critical walkability factors cound in literature.

Category	Level					Total per category
	Crossing	Pavement	Street	Environment	Weather	
Accessibility	9	20	3	8	0	40
quality	4	24	4	0	0	21
Obstruction	1	20	0	0	0	21
Route Attractiveness	1	7	17	21	11	57
Safety	8	0	10	4	0	22
Total per level	23	71	34	33	11	172

In the next table, a more detailed overview of the walkability criteria found on pavement level is given with detailed characteristics of pavement and objects in the way categories. Two walkability criteria are mentioned most: irregular surfaces and (wrongly) parked bikes and cars.

Table 4.2.: Detailed overview of criteria at pavement level.

Sub-Categories	Count	Detailed criteria	Count
Criteria about the pavement (availability and quality)	22	Presence of pavement	4
		Too wide or narrow pavement	3
		Irregular surface	13
		Slope	2
		Total	22
Criteria about curbs and ramps	12		
Stairs precense and quality	10		
Objects in the way	20	Parked bikes, cars, scooters (temporary)	8
		Physical stationary objects (poles trees ect.)	5
		Pavement objects (gutters)	3
		Temporary objects (commercial signs, branches)	4
		Total	20
Unatractive objects (litter, poop, garbage, graffiti)	7		
Total	71		

4.1.2. Summary personal interviews

Participant 1uses a wheeled walker already for 8 years. Without it she loses balance and so is really depended on the rollator. Short distances however are done often without the rollator but would be safer with. Although she has severe fright of falling, she walks outside at least once a day for half an hour to stay fit. But she would rather stay at home. Because when she gets tired her ankles weaken and she is even more afraid of falling. For her, if the pavements would be more smooth, she would be able to walk much further because it is more easy and she would not get tired that quickly. Loose tiles, pits, wrongly parked cars, tourists, sloping pavements are a problem to her. Also the amount of people on the street is something she tries to avoid. In conclusion, walking is not a relaxing activity for her.

Participant 2. Participant 2 is a real outdoor walker. She goes out on the streets several times a day and strolls around the whole neighbourhood. She uses the rollator for several years and feels that the rollator is really easy and a blessing for her. It keeps her mobile and enjoy Amsterdam around her. The problems mentioned by her are the uneven tiles or half loose tiles. So not well maintained pavements. Also when cars are parked wrongly it makes her move off the high curbs which is difficult. After asking for resting benches she mentioned that the hight of the resting benches are too low. So if she would sit on these she would have difficulty getting up again. She was really positive about the people on the street, in her perception they are friendly and helpful. Also she attached a bell on her rollator, so that if someone is in the way she would just ring the bell and she can pass.

Conclusion. Most often named:

- Irregular surfaces as in loose tiles or bad maintenance.
- Sloping surfaces
- Wrongly parked cars

4.1.3. Summary interviews at Rollator Loop

The age of the participants ranged from 77 to 94. Some used the rollator for more than 6 years, while others only since half a year. When starting using a rollator, participants said they did not dare to walk without it any more, because of fear of falling. Most of them mentioned grocery shopping as the main activity for using a rollator outdoors, for it is easy to put the groceries in. Participants and their accompaniments said that you only notice the bad quality of the streets when your mobility worsens and you start needing a rollator to help you. Problems mentioned were; roots of trees make the pavement uneven, pavements are convex and these sloping circumstances need you to adjust the rollator all the time. The maintenance is not sufficient. Not nicely finished pavements, transition from tiles to asphalt not even, public transport stops not adjusted or tram rails. Sloping pavements and bad maintenance as in uneven surface, were mentioned several times. Positively mentioned was that there is enough space to walk. Not all participants have difficulty with going on and off the pavement. One participant did not have any problems while walking on the street while walking to the grocery store across the street a few times per week.

Conclusion. Most often named:

- Irregular surfaces as uneven pavements or bad maintenance.
- Uneven transition of road segments.

4.1.4. Findings Amsterdam policy and summary interview municipality

From the interviews with members of the Amsterdam municipality, working on Transport and Public Space, we learned that the pedestrian is not a main focus for the design in the public space. For the Amsterdam municipality the focus goes to the growing number of tourist in the centre and on accessibility of public transport and public buildings. Interventions done to increase accessibility for pedestrians is placing more post on the pavements and raise the pavements to avoid cars parking there. Also public transport stops are all raised for easier entrance into the bus and trams.

For the future, the municipality is working on a new framework for pedestrians. The first stage to be completed at the end of 2015. The framework will include the design policy for public space with principals, assumptions, guidelines, goals, test and products. All to make the pedestrian more visible, measurable and comparable. It will be a integrated pedestrian policy, covering everything to do with pedestrians, form crowd management to accessibility. The goal is to grow and give more space for pedestrians, to increase the use of the public space. This new design is part of the restructuring inside the municipality, before the policy design for the public space was scattered over districts, now it is brought back to one central governmental body inside the municipality.

When informing to existing geodata about pedestrian area, surface material and curb locations, nobody could tell exactly what and where the data was and if, even existed. There is use of geodata at the municipality, though nobody could tell exactly what.

A document of 2011 about the guidelines for the Central Traffic Commission in Amsterdam, provides a lot of guidelines in the public space for the pedestrian. The following guidelines are given especially for the less mobile pedestrian:

1. A minimum free passage width of $1.50m$ is necessary.

2. If pedestrian use is very high, the minimum free passage width of $2.50m$ is necessary.

In practice a lot of extra space is needed to place all street furniture. Therefore an extra space of $0.5m$ has to be added as 'smart' strip to place lanterns, poles, benches, garbage containers etc. Preferably $1m$ if shops have protruding displays at the building side. An extra $1.80m$ is needed when bike racks are placed on the pavement. [40]

For more research on this topic, Verschuur 2013, looked at these guidelines in a case study in Utrecht. [46]

policy guidelines for pedestrians found for Amsterdam

- More safety for the pedestrian [11]

- More space for the pedestrian [11]

- in the centre of Amsterdam, give the pedestrian the most safe and attractive public space with the least amount of obstacles and delay. [27]

- Inside the highway ring, provide wide pavements and safe crossings. [27]

- Design more logical, straight, obstacle free ongoing walking routes on the pavement [4]

- Reduce hight differences in tile work and minimize the use of stairs and ramps in the public space. [4]

4.1.5. Final list critical factors

The top 3 critical factors that decrease walkability derived from all of the above are:

1. Wrongly parked bikes and cars

2. Sloping pavement

3. Irregular pavement

The first item will not be examined, for parked bikes and cars are temporary obstacles which can be hard to detect through stationary geo data. The applicability of Geo information systems for monitoring wrongly parked bikes and cars is a whole new study on its own.

4.2. Results RQ 2 - Collection and analysis of available geodata

4.2.1. Average walking speed

Based on the Rollatorloop of 2014 and 2015, an average walking speed of $4.62km/h$ was found. The routes walked all started in the athletics track in the Olympic stadium. The $400m$ was only using the athletics track so had an extreme good, flat and regular surface. The $1000m$ route went round outside the stadium over the street and pavement, so had a less smooth surface. The third route $2500m$ even went through a park with soft gravel, so had the least best surface but was acceptable for rollator users. Overall the weather conditions were extreme good. In the table 4.3 and figure 4.1 can be seen that the average walking speed decreases when walking longer distances. The total number contains all participants labelled as male, female or unknown. Therefore, the sum of male and female differences from the total number.

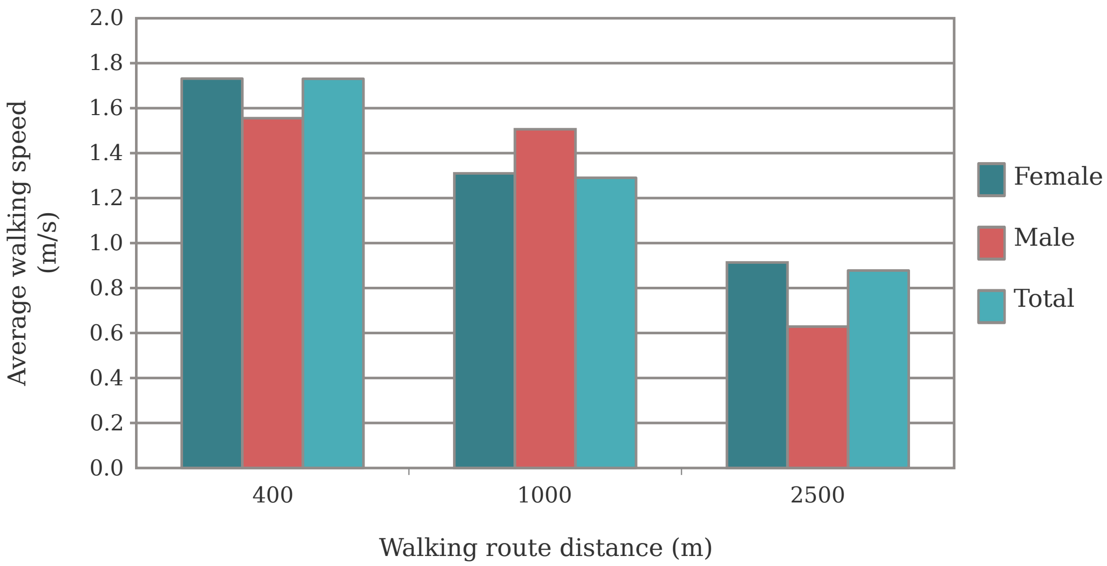

Figure 4.1.: Average walking speed of the participants from the Rollatorloop (2014 and 2015).

Table 4.3.: Average walking speed of the participants from the Rollatorloop (2014 and 2015)

Distance	Sex	Count	m/s	km/h
400	Male	25	1.56	5.60
400	Female	97	1.73	6.23
1000	Male	5	1.51	5.42
1000	Female	28	1.31	4.72
2500	Male	1	0.63	2.26
2500	Female	7	0.91	3.29
	Total	179	1.30	4.62

4.2.2. Determining pedestrian area with the GBKA

The GBKA was used to determine how much surface is determined for pedestrians, the road segments are given a new attribute with our own classification: 1 for transport, 2 for pedestrian area and 3 unpaved areas. In annex A.8 the total area of the Jordaan is shown with our derived classification. Here, a detailed map shows of an area where the classification turned out to almost correct, but also contains streets which area wrongly assigned as pedestrian area. In total, the Jordaan has around $300000m^2$ of public road surfaces. About 53% of this is intended for pedestrians according to the developed approach. This share of road does contain poles, lanterns, bicycle racks, parking lots and all other street furniture.

Table 4.4.: Road segment classification outcome.

Road Section	Total Area	Percentage
All Road Sections	293317.25	100.00
1. Transport	133789.66	45.61
2. Pedestrians	156159.49	53.24
3. Unpaved	3368.1	1.15
Below 4% slope	114341.08	38.98
Pedestrian below 4% slope	24466.67	8.34

Figure 4.2 shows in white, the pedestrian area as approached. The street Tweede Boomdwarsstraat is wrongly classified as well as most bridges. The parking lots in the centre of the road Westerstraat are labelled as pedestrian area but are not suitable for pedestrians as it is full with cars and other street furniture. See Figure 4.3 image from Google street view of the Westerstraat.

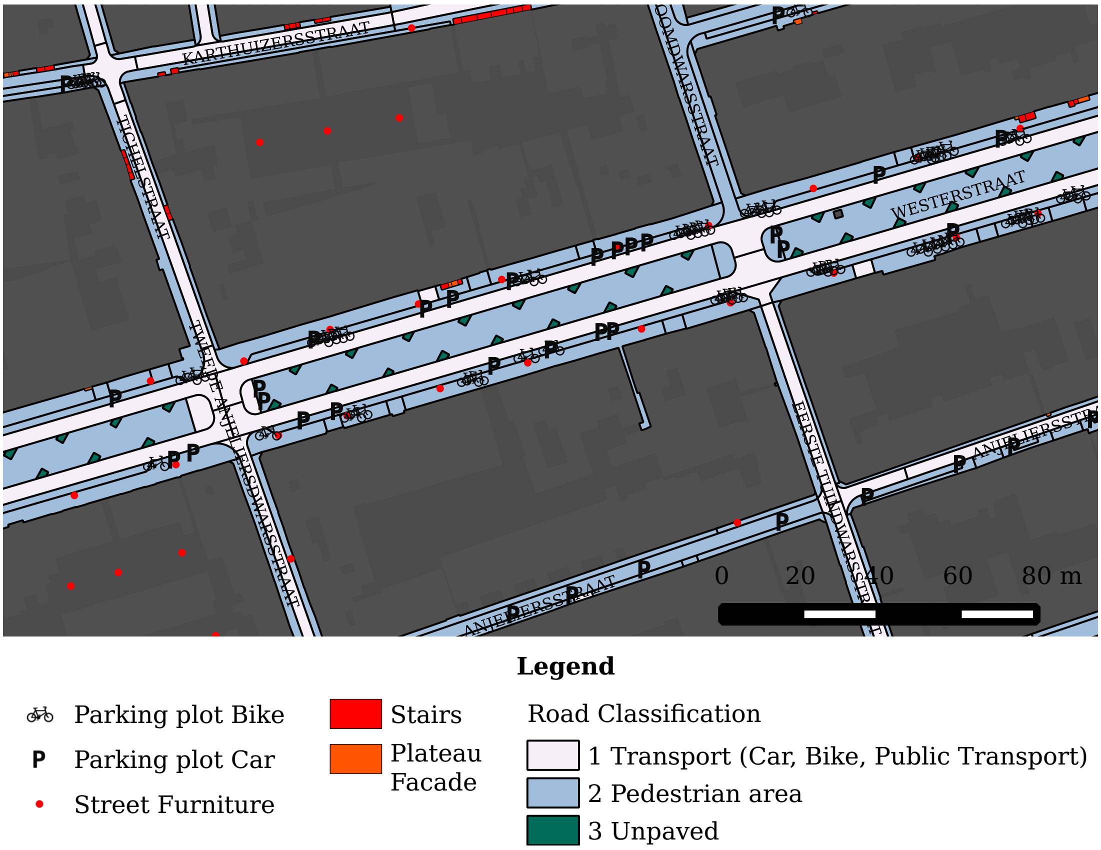

Figure 4.2.: Detail segment classification in the Jordaan(Westerstraat).

Figure 4.3.: Google Street View image of the Westerstraat.

4.2.3. Mapping sloping surfaces with AHN data

In table 4.4 from the previous section, also the area of pedestrian area with a slope lower then 4% and the total area below 4%slope is given. Those are consecutively, 8% and 39% of the total area. The top part of figure 4.4 the Westerstraat can be seen with the slope below 4% in green. The roads destined for cars mostly show green colour except for the speed bumps which can be clearly distinguished. The pedestrian area on the other hand, shows more red spots. The bottom part of figure 4.4 shows the average slope per road section polygon. Mostly the car area (1) stays below the 4% mark while the pedestrian area (2) has higher slopes. Curbs and objects placed on the pavement give a hight slope value and fall in the pedestrian polygons. Building edges which are not cleaned away well enough can give a wrong impression of the pedestrian polygons. The original hight map of the AHN2 can be found in Annex A.9.

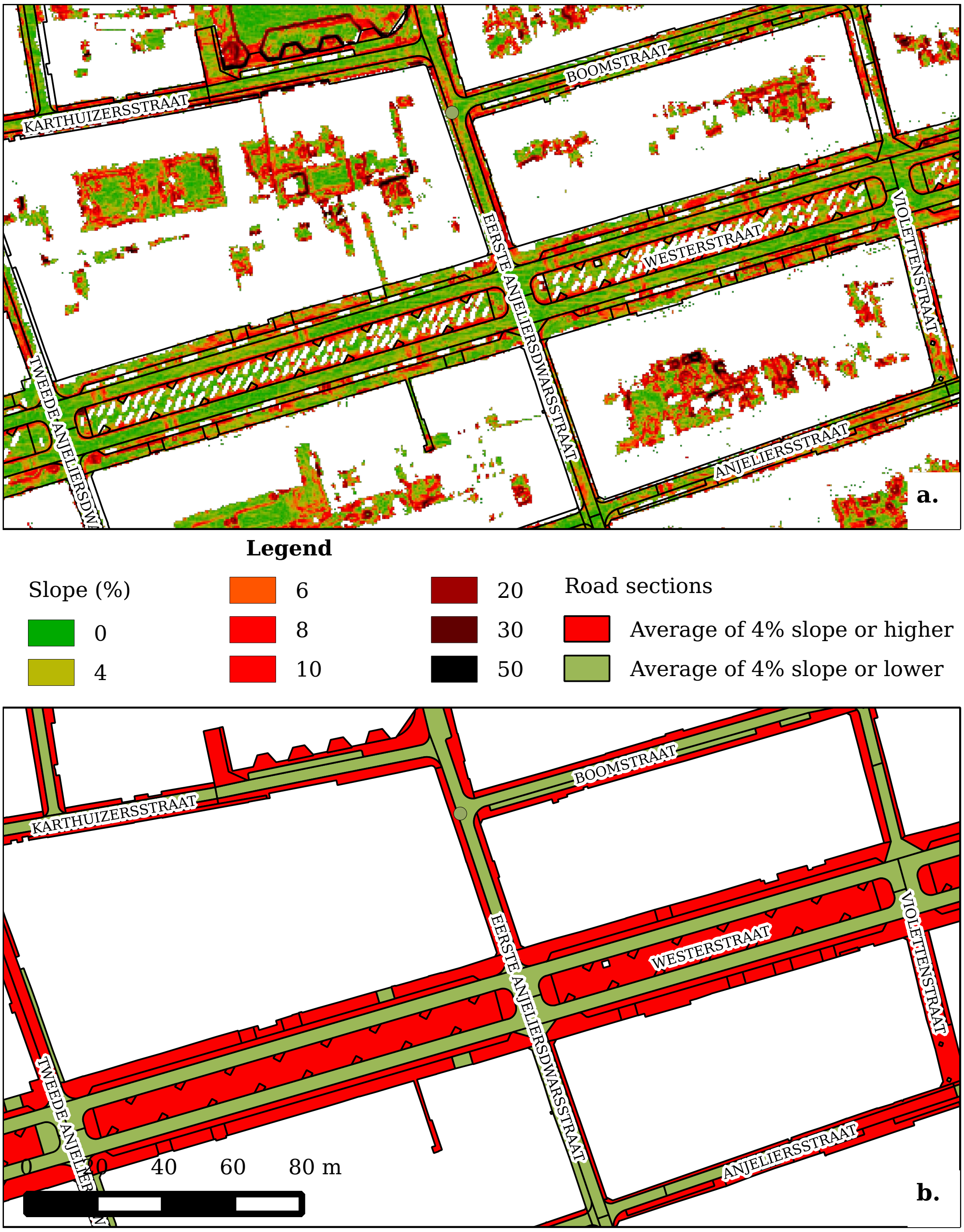

Figure 4.4.: Detail of slope and average slope per road section in the Jordaan(Westerstraat).

4.3. Results RQ 3- Collection of geodata of rollator movements and analysis

4.3.1. Mapping irregular surfaces with an Accelerometer

Figure 4.5 shows the accelerometer output of the z-axis per measured surface. The exact statistical summary of every surface is given in table 4.5 containing the total acceleration mean, standard deviation, the variance, the minimum and maximum, first and third quantile and the median. The median and mean are roughly the same for every surface, because the accelerometer measures acceleration in the vertical direction around $1m/s/s$, which is equal to gravity. Any acceleration aiming up will also go down. The extent of acceleration a surface causes in the vertical direction, or the standard deviation or variance, tells more about the differences in surface. The box plots 4.6 show the differences in variance per surface. A clear difference per surface type can be seen. The smooth concrete, gave almost no acceleration in the vertical direction, while stones or grass showed more vibration and so higher and lower values in minimum and maximum as well as the standard deviation and variance.

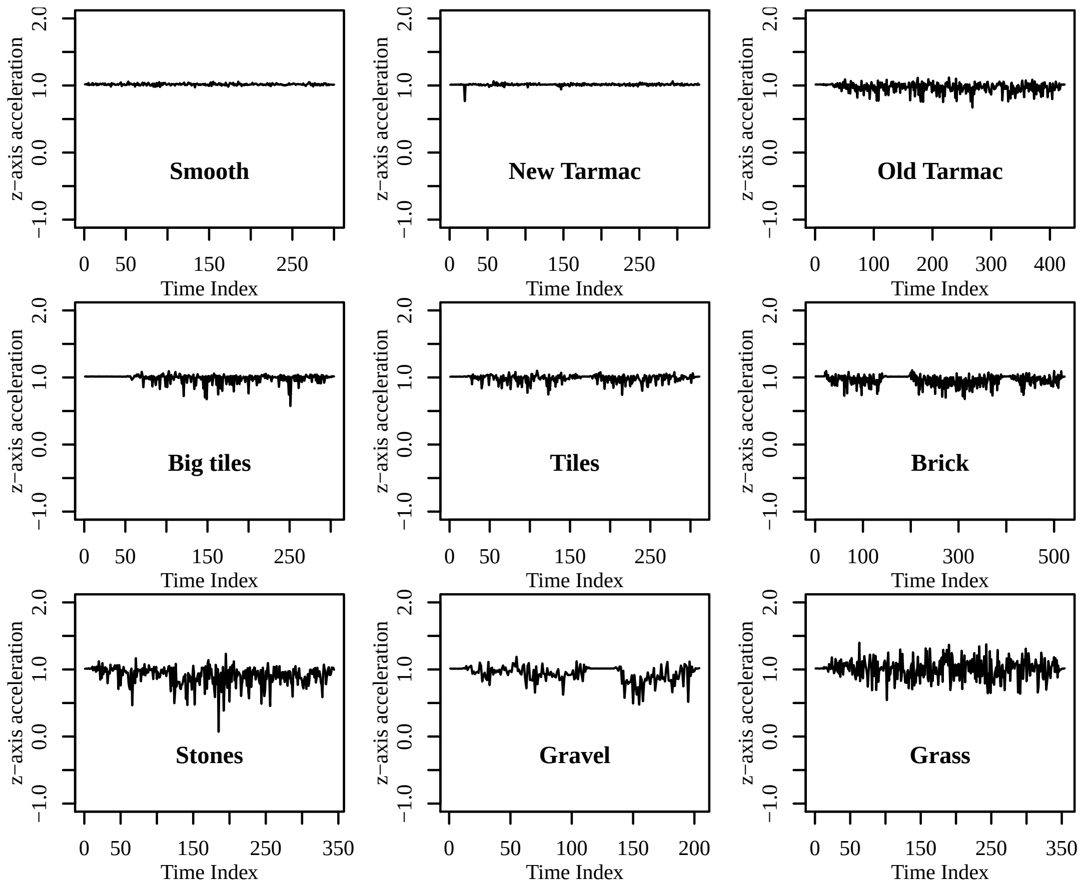

Figure 4.5.: Accelerometer output of the z-axis per surface type.

Table 4.5.: Statistical summary of z-axis acceleration per surface type.

Surface:	Mean	Std dev	Variance	Min	Q1	Median	Max	Q3
Smooth	1.02	0.02	0.00	0.97	1.02	1.06	1.01	1.03
New tarmac	1.01	0.02	0.00	0.77	1.01	1.06	1.01	1.02
Old tar-mac	0.97	0.07	0.01	0.67	0.99	1.12	0.94	1.02
Big tiles	0.99	0.07	0.00	0.58	1.01	1.10	0.98	1.02
Tiles	0.99	0.06	0.00	0.74	1.01	1.10	0.97	1.02
Brick	0.96	0.07	0.01	0.68	0.98	1.11	0.92	1.01
Stones	0.91	0.14	0.02	0.07	0.94	1.23	0.84	1.01
Gravel	0.94	0.12	0.02	0.48	0.97	1.19	0.87	1.01
Grass	1.01	0.15	0.02	0.54	1.02	1.40	0.93	1.10

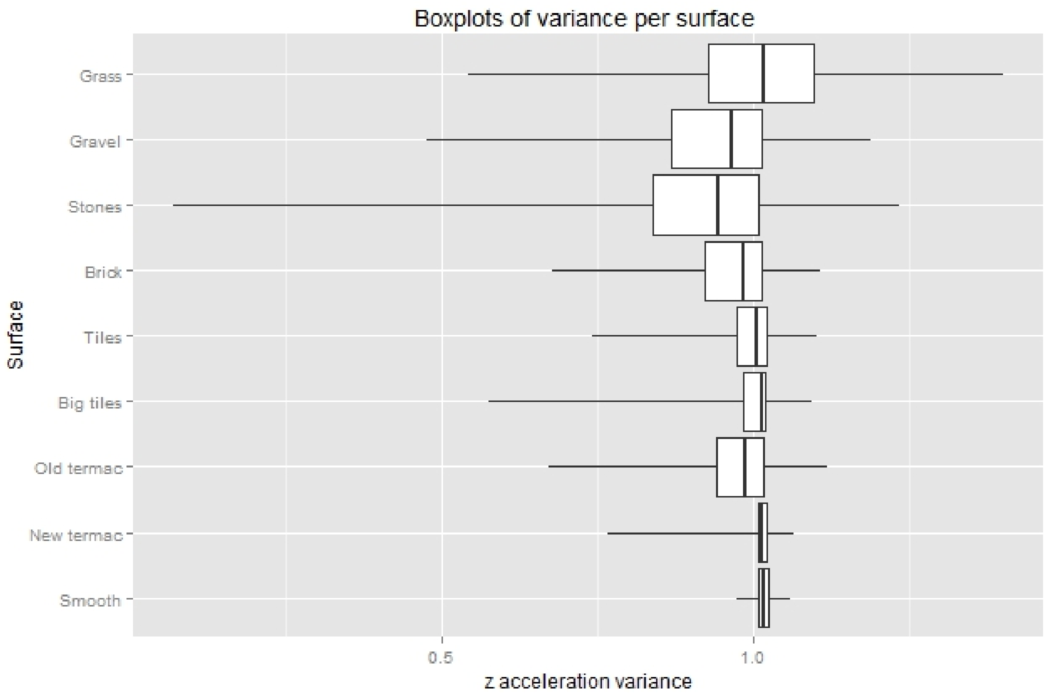

Figure 4.6.: Box plots showing the variance per surface type.

4.3.2. Comparison with Matthews et al. 2003

From the standard deviation relative scores are assigned. The value 1 is assigned to the smooth surfaces as basis. The other values are calculated as a factor from this. Lower scores represent levels of least hindrance while higher scores represent high levels of vibration and more hindrance. These factors are compared with the results of a similar study by Matthews et al.(2003) and matched upon the surface description. The factors from Matthews et al. do differ in value but are also calculated relatively to its most smooth surface, concrete. When plotting both values against each other a correlation coefficient of 0.72 is found. This indicates a positive but moderate correlation between the two data sets. This proves that the surface coarseness or irregularity can be determined with an accelerometer.

Table 4.6.: Relative scores of surface hindrance as measured and from Matthews et al.

Surface	Standard Deviation of z-ax	Percentage	Factor	Factor given by Matthews	Surface name by Matthews
Smooth	0.01	100.00	1.0	1	Concrete
New tarmac	0.02	132.72	1.3		
Old tarmac	0.07	489.01	4.9	1.3	Tarmac
Big tiles	0.07	467.30	4.7		
Tiles	0.06	404.02	4.0	1.2	Paving
Brick	0.07	510.27	5.1	1.6	Brick
Stones	0.14	1000.62	10.0		
Gravel	0.12	857.41	8.6	8	Gravel
Grass	0.15	1037.63	10.4	6	Grass

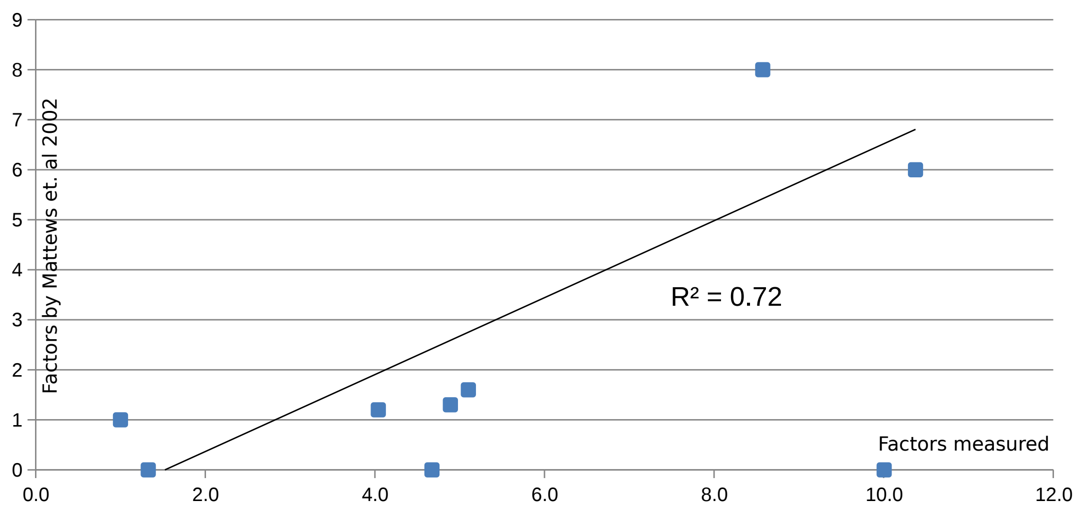

Figure 4.7.: Comparison factors measured and factors given by Matthews et al.

4.4. Results RQ 4 - Mapping abnormal or change events with Accelerometer, GPS and AHN2 data

4.4.1. Comparing different changepoint detection methods

First, the different changepoint detection methods and penalty values had to be tested to see which model approaches the most plausible result and approaches the truth the best. This was shortly done for all datasets. Here we will show possibilities of the acceleration output of the $z - ax$ of the rollator route in detail. See figure 4.8 Walking with a speed of around $4km/h$, the distance between each measured point is around $25cm$ with a sample frequency of 5 points per second (Normal settings). The total route was 500 meter.

The first method, finding changepoints for the variance with PELT method, resulted in 10 changepoints. So on average one changepoint per 100 meter. Some outlying peeks are missed by the model, and are not enclosed by changepoints, while they could indicate an unevenness in the surface.

The second method variance with PELT $1.5 * log(n)$ resulted in 69 points. On average one point per 7 meter. Now, the outlying peaks are enclosed by two changepoints, indicating exactly where a abnormality happens. Changing the penalty value solves the problem of over-fitting the model. The penalty increased the number of parameters in the model and almost always improves the goodness of fit.

Method BinSeg and BinSeg $1.5 * log(n)$ took a longer computing time and resulted in only 5 changepoints for the variance. Method PELT and PELT $1.5 * log(n)$ for the mean resulted in no changepoints. Method SEGNeigh on the mean of the variance didn't gave any output. The PELT method for both the mean and variance at the same time had 50 changepoints.

Thus, for detecting changepoints in the variance of the acceleration the PELT method with a manual pen value of $1.5 * log(n)$ is used to overcome over and under fitting. For it showed the most plausible result.

A same kind of figure for the analysis of the best methods to detect changepoints in the speed dataset, can be found in annex A.10. For the speed we look at changes in the mean.

Significant changes are, that the speed drops 2 times almost to the zero, the first drop is seen when walking up and down the pavement curb. The second drop coincides with a curve in the road where probably a short stop was made.

The first method, finding changepoints for the mean with PELT method, resulted in 3 changepoints and missed the second drop in speed. The second method variance with PELT $1.5*log(n)$ resulted in more points and did detect the second drop in speed. Plus, it broke up the first stop into 3 parts. Method BinSeg, BinSeg $1.5*log(n)$ and SEGNeigh resulted in no output.The PELT method for both the mean and variance at the same time had made a break point on every value of a change in speed, therefore over-fitted the model. When looking at the changepoints in the variance, PELT and PELT $1.5 * log(n)$, detected more changepoints. Sometimes giving a logical breakpoint, for example at the huge drop in speed. But it also detected multiple points really close to each other, singling out steps in gradual decrease or increase of speed over a longer distance. This gives too many points: every 5 meter.

For every individual dataset, the best possible penalty settings are considered, for there can be a big difference in characteristics of the dataset for speed, slope and acceleration. Though, for all datasets, the PELT method was used, because of quick computing time and good accuracy and distribution of changepoints over the dataset. In general the slope datasets resulted in too much over-fitting, therefore a different penalty type was chosen, the AIC or the BIC model. For every dataset the model of fit is indicated in the summary tables of the next section.

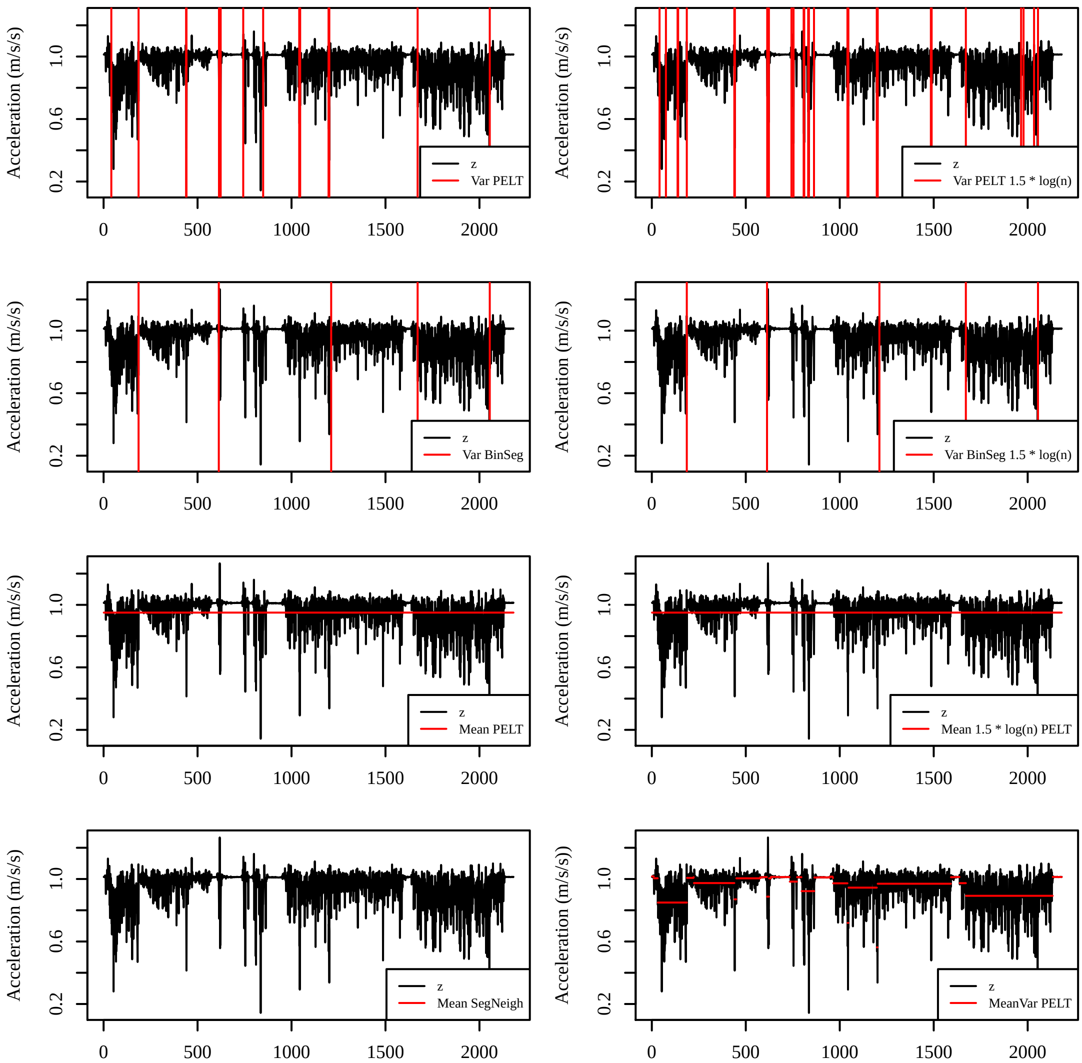

Figure 4.8.: Comparison of different algorithms for changepoint detection in accelerometer z-axis output.

The next sections show the changepoints detected for average height, average speed, average slope, and variance of the total acceleration for all the measured routes. The changepoints are assigned to a location through linking its time stamp with the time of the GPS data.

4.4.2. changepoint and Segments found for the Meetrollator walking route

In figure 4.9 the route of the measurement rollator is shown with the detected changepoints indicated. The numbers show the time index which is the same as found in the graph 4.11, which shows the datasets with the changepoints and segments. The average walking speed was $1.2 m/s$.

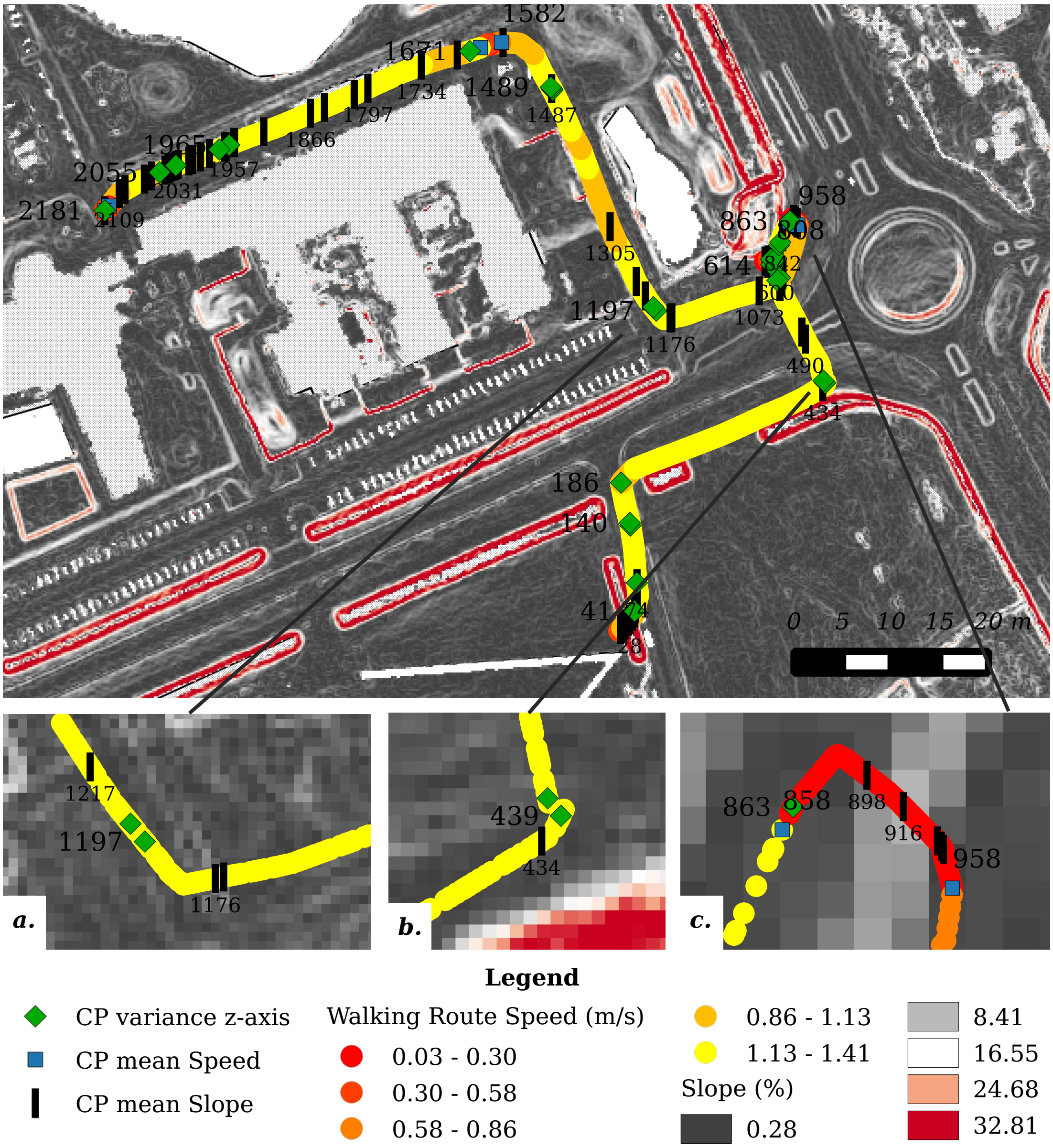

Figure 4.9.: Map with changepoints of the Meet Rollator route.

The right zoomed in square shows the area where a little detour was taken, walking down and up the curb again. The slope map clearly shows the location of the curb and the pavement. Specifically in the top, the crosses show a decrease and increase in speed while going over the curb. The red dots show a change in slope where the curb is located. Only no change in variance is detected. The left zoomed in square shows again that the changepoint in slope is detected, where the little red dots and the slope map show a bump. Though the changepoint in the accelerometer fall slightly later in the route. The slope is derived from the location of the track, while the accelerometer is linked to the time stamp of the GPS. Because of GPS inaccuracy's these points do not have to fall at the same point in the route.

Figure 4.10.: The surface with obstacle from detail (b) figure 4.9

Table 4.7.: Summary of changepoint output and methods used, per dataset, for the MeetRollator walking route.

	Slope	Speed	Variance z-axis	Variance total acceleration
Changepoint type	Change in mean	Change in mean	Change in variance	Change in variance
Method of analysis	PELT	PELT	PELT	PELT
Test Statistic	Normal	Normal	Normal	Normal
Type of penalty	Manual with value 11.53131	Manual with value 11.53131	Manual with value 11.53131	MBIC with value 23.06262
Minimum Segment Length	1	1	2	2
Maximum no. of cpts	Inf	Inf	Inf	Inf
Number of changepoints	69	7	28	12
Created Using changepoint version 2.2				

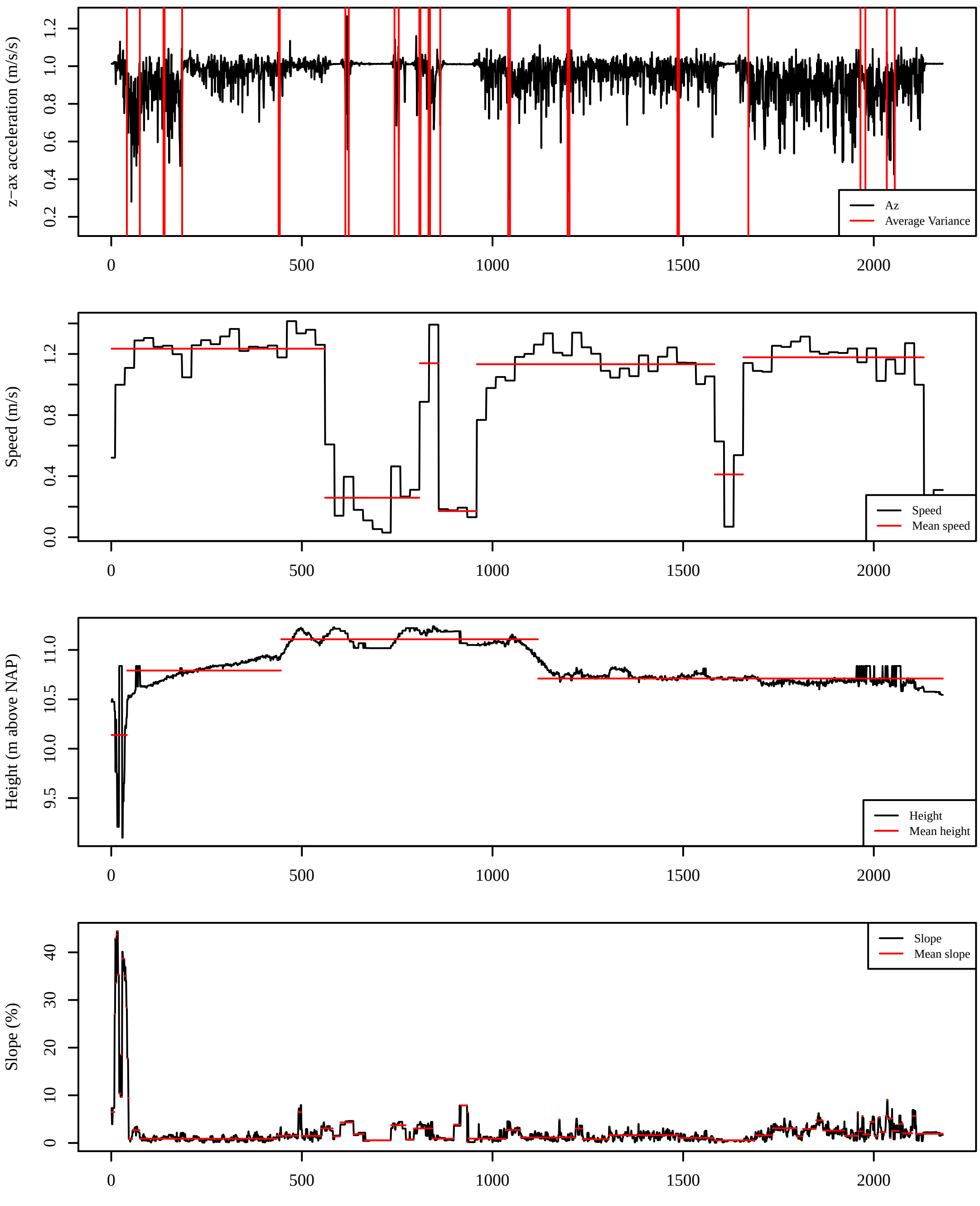

Figure 4.11.: Changepoint segments per dataset of the MeetRollator route.

4.4.3. changepoint and Segments found for the Leica walking route (without accelerometer)

From the failed measurements there was one route walked with a Leica system. Though, there are no accelerometer measurements available for this route, the GPS-location is more accurate and the comparison of slope and speed could potentially give better results.

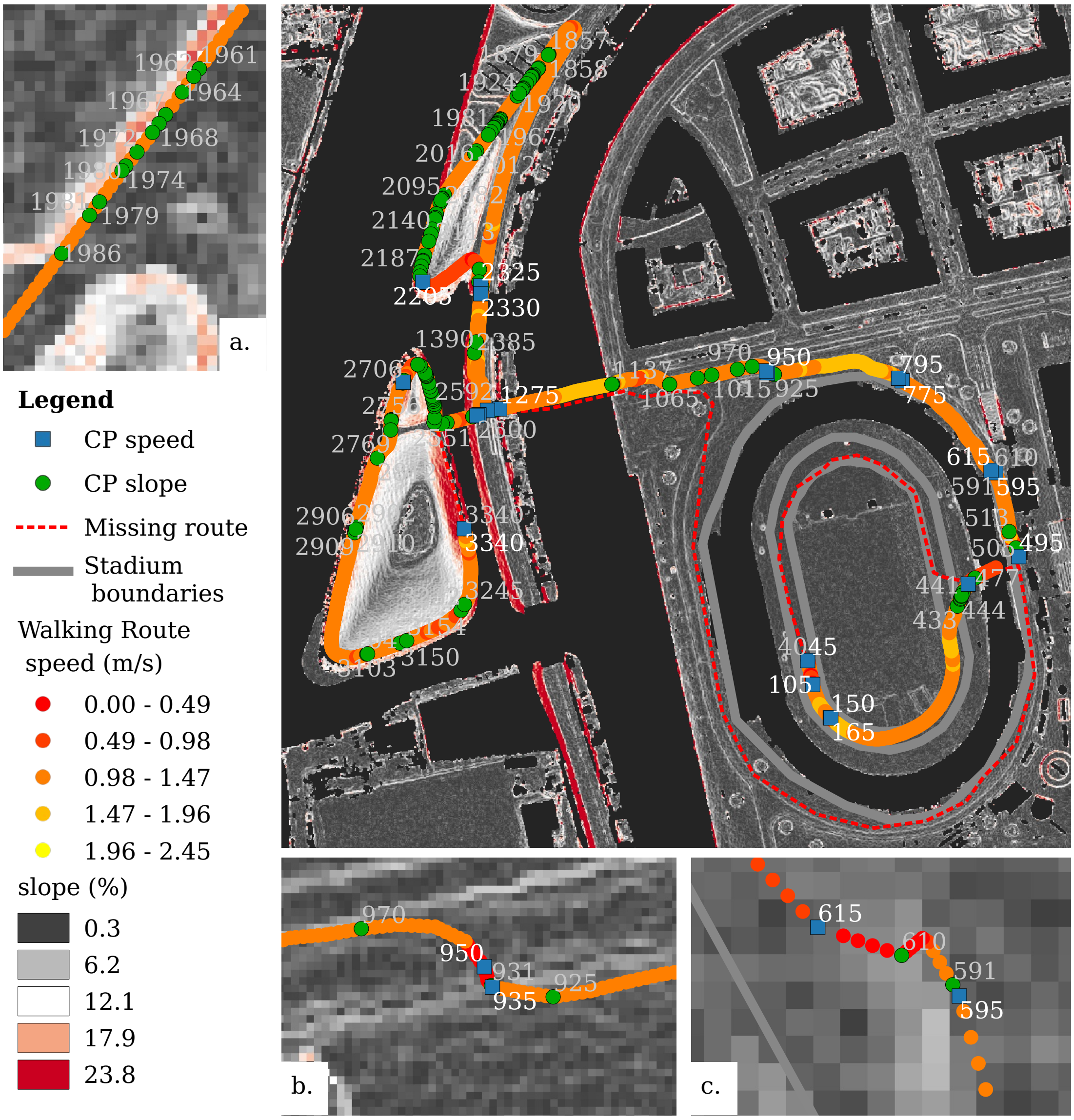

Figure 4.12.: Map with changepoints in speed and slope for the Leica route.

Figure 4.12 shows the complete route, starting in the stadium, going outside to the park and returning to the stadium. The Leica measurements stopped halfway the route and was not noticed by the user. This part is indicated with the red dotted line. The start of the route shows three changepoints in speed, a increase from standing still to walking. For the rest, the part of the route on the athletics track did not show any irregularities in slope or speed. The first interesting point is shown in the detailed map (c). The participants walked on the bicycle lane and realized to go onto the pavement, which are separated by a curb. The participant clearly slowed down and took the obstacle. Both changepoints in the speed and slope enclose this curb challenge. The detailed map (b) also shows a change of road segments. Again showing the same pattern in speed. Slowing down the speed, taking the curb obstacle and increasing speed again. Only here the changepoints for slope are positioned outside the speed changepoints. Detailed map (a) shows a part of the route in the park with a grassy hill in the middle which is enclosed by walking paths. A lot of changepoints in the slope are detected because the position of the measured route is slightly off the path and located n the edge of the hill. Of course the participant did not walk with his rollator on the edge of the hill, but on the middle of the path. Therefore these changepoint can be labelled as wrongly classified.

Table 4.8.: Summary of changepoint output and methods used, per dataset, for the Leica walking route.

..	Slope	Speed
changepoint type	Change in mean	Change in mean
Method of analysis	PELT	PELT
Test Statistic	Normal	Normal
Type of penalty	MBIC with value, 24.34118	AIC with value, 4
Minimum Segment Length	1	1
Maximum no. of cpts	Inf	Inf
Number of changepoints	123	20
Created Using changepoint version 2.2		

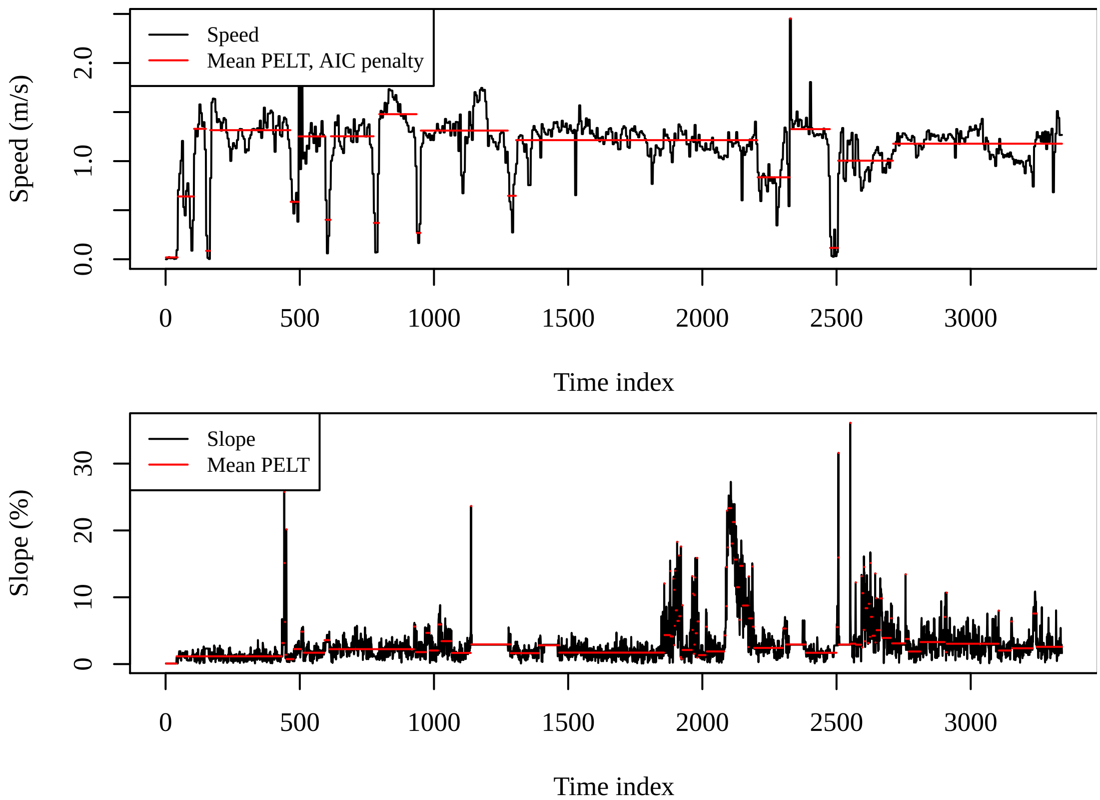

Figure 4.13.: Changepoint segments in speed and slope for the Leica route.

4.4.4. changepoint and Segments found for the bike route

For testing the accelerometer application, a route with GPS and the accelerometer app was conducted on the bike. This resulted into the following data. Figure 4.15 shows the route with the bike in the big top map. The left zoom squares (a) and (b) show a crossroad, where the bike path is interrupted by another type of road changing from concrete to tiled paving. As can be seen the speed shows changepoints before and after this crossing, where I slowed down with the bike to take the curves and check for upcoming traffic. Also a changepoint in the accelerometer is present, this could indicate the change of surface material and the little gap/border where the pavements change. We would have expected two changepoints, one going off the asphalt lane onto the crossing and one leaving the crossing going up the asphalt bicycle lane again. Unfortunately this is not the case. See figure 4.14 showing a Google street-view of the bicycle lane pavement changing to tiles at the crossing.

Table 4.9.: Summary of changepoint output and methods used, per dataset, for the cycle route.

..	Slope	Speed	Variance z-axis
Changepoint type	Change in mean	Change in mean	Change in variance
Method of analysis	PELT	PELT	PELT
Test Statistic	Normal	Normal	Normal
Type of penalty	MBIC with value, 24.5802	Manual with value, 12.2901	Manual with value, 12.2901
Minimum Segment Length	1	1	2
Maximum no. of cpts	Inf	Inf	Inf
Number of changepoints	195	27	32
Created Using changepoint version 2.2			

Figure 4.14.: Google street-view of the cross road from map (b) figure 4.15.

The right square (c) shows a street with speed bumps that have to be crossed with the bike as well. The vertical acceleration changepoints indicate roughly these bumps and no change in speed is detected. Which is logical, because with a bike you do not really slow down for moderate speed bumps. A lot of changepoint in the slope come up but they do not indicate the speed bumps for the location was not accurate enough and the route is mapped next to the road several times.

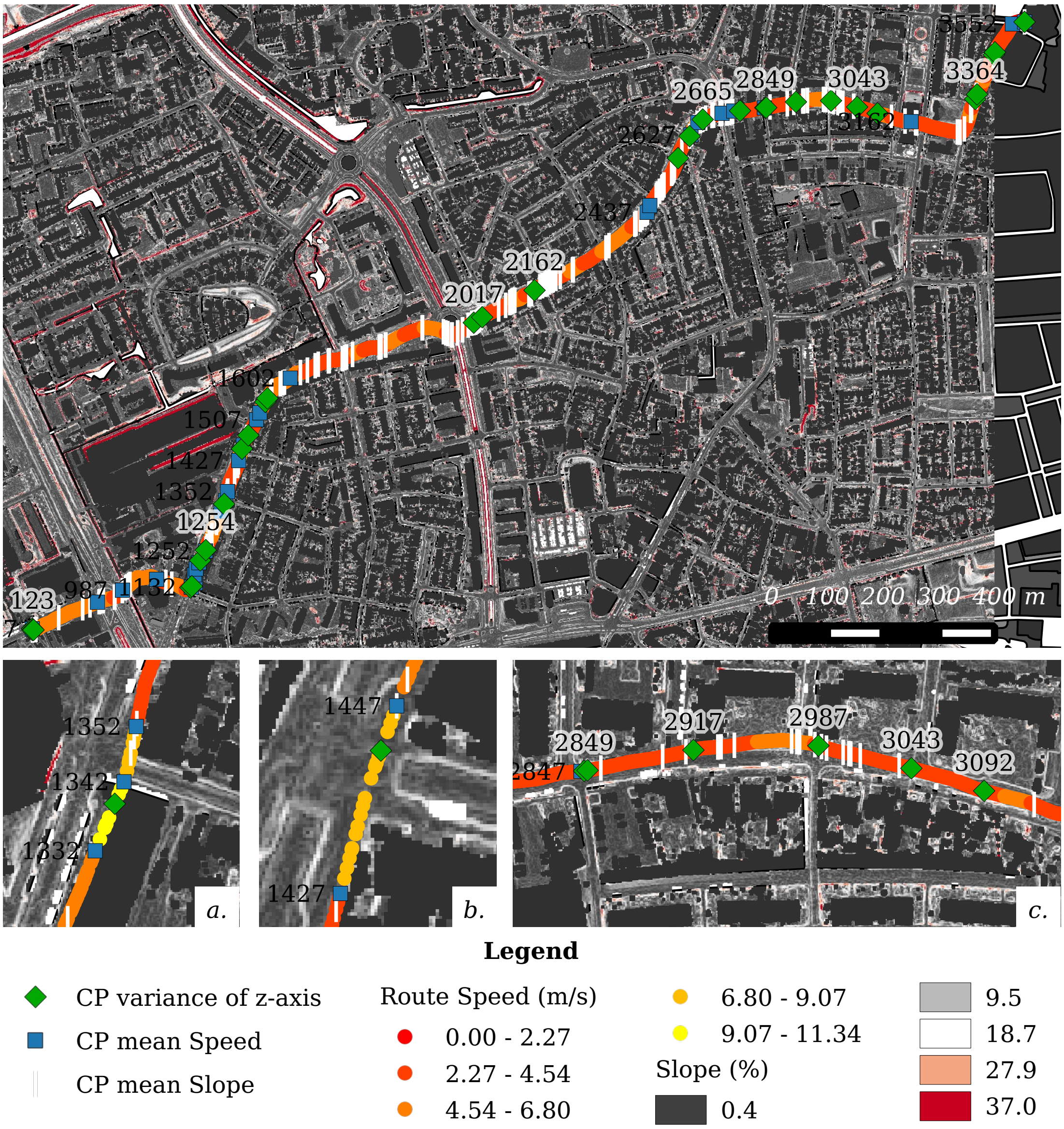

Figure 4.15.: Map with changepoints of the bike route.

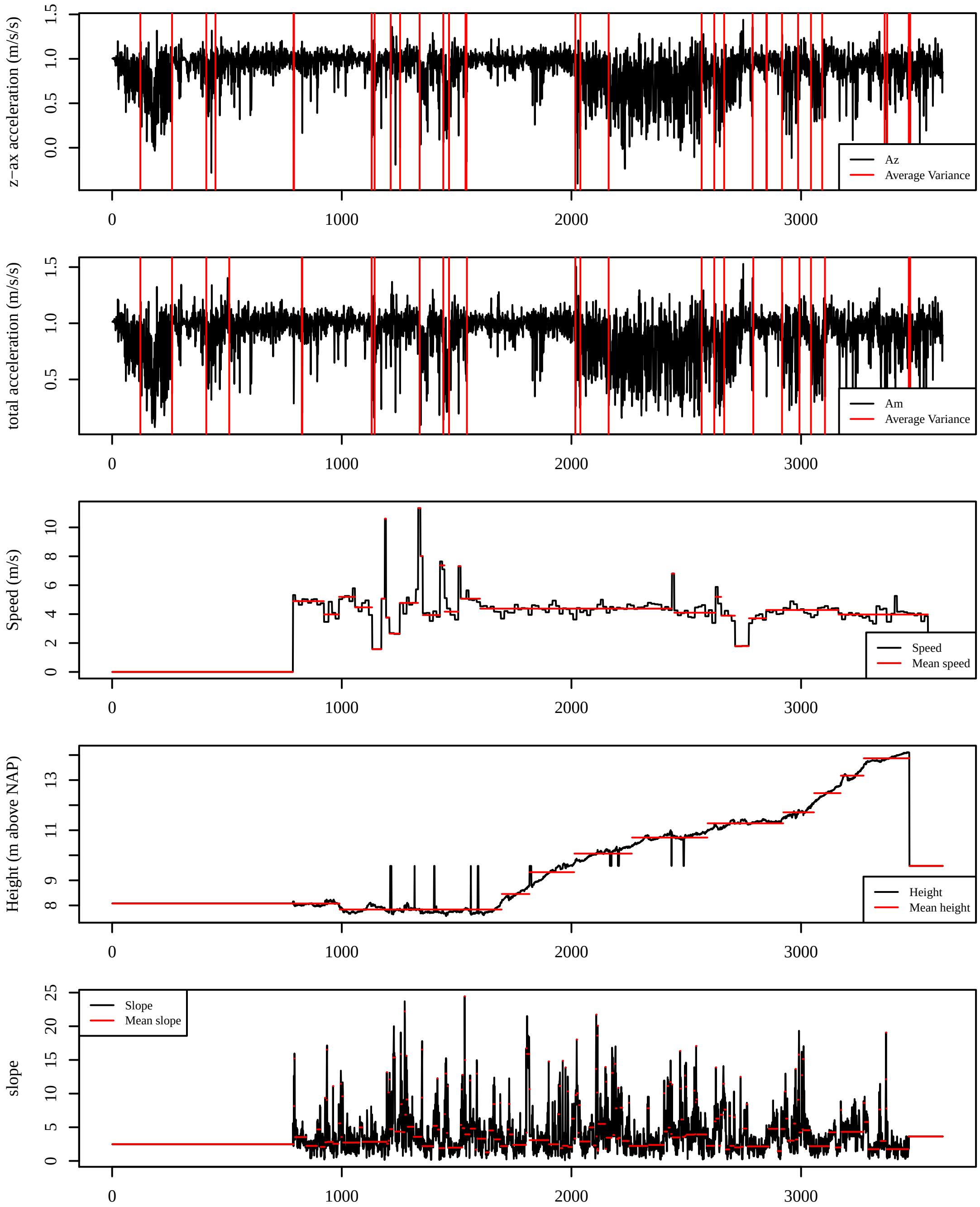

Figure 4.16.: Changepoint segments per dataset of the bike route.

5. Conclusion, discussion and recommendation

The first section of this final chapter restates the research questions and presents the main conclusions of this research. Section 5.2 discusses the outcomes and limitations of the research. Section 5.3 gives several recommendations to improve this research and for possible future research.

5.1. Conclusion

The objective of this research is to analyse and visualize geodata to explore the critical walkability factors for elderly dependent on a rollator in the urban outdoor space. With the goal to raise more awareness and shed more light on the forgotten elderly pedestrian. To achieve this objective, the following research questions were answered:

1. The first research question found the critical walkability factors hindering elderly with a rollator in the outdoor environment.

2. These critical walkability factors were mapped and analysed with existing geodata in research question 2.

3. Research question 3 collected own geodata with a smart walker to map and analyse these critical walkability factors.

4. In the end both the available and the measured geodata are compared in research question 4.

The most mentioned critical walkability factors found in literature study and interviews were, wrongly parked bikes and cars, irregular cobbled surfaces and sloping pavements. There are many criteria mentionable to improve walkability for the elderly pedestrian. User experiences and own experiences used in this research underline the importance of the quality of the pedestrian area. The most important thing mentioned by rollator users is with smoother surfaces and less exhausting surroundings, longer and more comfortable walks can be made. This research found walkability factors in line with previous researches and contributes to the knowledge specifically for Amsterdam. One of the main irritations specifically for Amsterdam are wrongly parked bikes and cars, mainly due to the small pavement areas and parking on the pavements. Also, many road users hardly think about the less impaired road users while parking their bike outside against a lantern pole and thus block the pavements for wheelchair or rollator users.

The research of the policy design and interviews with the municipality showed that policy design does not take pedestrians into account sufficiently, let alone the elderly or mobile impaired pedestrian. There was no data available on elderly pedestrians and no data collected at the decentralized governmental level, which is responsible for the design of the public space. Currently the people that we corresponded with, working on public space design, are not aware of any data on pedestrians or where to possibly find it.

When looking at available geodata for walkability, there was no dataset at the Amsterdam municipality on the location of curbs, their height, where ramps are placed or where the curb is lowered. Also they could not provide information about the exact type of material of the surface or maintenance activities. We did collect one overview map showing material use on neighbourhood level, see the Puccini map in annex A.3. The only data available was the GBKA showing a detailed topology map of the centre of Amsterdam. Labels indicating pedestrian area are missing.

Guidelines about the design of pavements were found in a report from 2011. [40] If these guidelines are followed in Amsterdam is not sure. The study by Verschuur (2013) developed a method to test the implementation of these guidelines in a case study for Utrecht, the Netherlands. In order to do this, a basic geodata layer is needed showing the pedestrian area. Also the works of Matthews et al. (2003), Modelling Access with GIS in Urban Systems [30], Svensson (2010) [42] and Duncan et al. (2011) with Walk Score: Estimating Neighbourhood Walkability [18] provide methods for quantifying walkability factors in a GIS system. They use a multi-criteria model with quantitative and qualitative techniques to make visible how the build environment can be hostile for the mobile impaired and need a basic geodata layer about the area used for pedestrians. To see if this could be derived from the available GBKA an own approach is developed to determine which areas are pedestrian area. It showed high numbers for pedestrians: around 53% of the public space in the test area Jordaan, belonged to pedestrians. This is a surprising high amount because often in Amsterdam pedestrians pavements are very narrow. The assumptions made in the classification, included parking lots and public squares within the pedestrian category. Also, pedestrian area often contain a lot of poles, bike racks, traffic signs or any other object placed on the pavement. The GBKA showed that the available geo-data of the municipality still lacks detail and information and is not suitable for quick pedestrian area analysis. This confirms the statements of the introduction that pedestrians are missing in data.

Mapping the slope with the AHN2 to derive sloping pavements above 4% showed that a lot of pavements classified as pedestrian area had an average slope higher than 4%. While road segments classified for motorized transport showed average values below the 4% slope. The 4% slope rule, reduced the optimal pedestrian area to only 8% of the total surface, including parking lots and public squares. This shows that a lot of area is too steep for pedestrian allowable limits and can be labelled as unsuitable. In conclusion, the walkability criteria of sloping pavements can easily be mapped with the AHN2.

Mapping the walkability criteria with our own smart walker was done by measuring location and rollator vibrations with a GNSS and Accelerometer. The works from Weiss et al. 2014 and Wang et al. 2015 [49, 48] gave the inspiration to work with the concept of a Smart Walker. Several test routes were walked during the rollator loop but failed to measure the accelerometer sensor and were therefore not usable. A second test did succeed and the rollator measuring different surfaces showed that irregular surfaces can be measured with an accelerometer. The different kind of surfaces showed clear distinctions in the amount of vibrations when looking at the variance over the measured track. Grass and stones have the highest variance and vibrations and smooth concrete the lowest. When comparing our results to a similar research done by Matthews et al. (2003) a moderate correlation of 0.72 is found.

In order to compare the existing geodata to the measured geodata a changepoint analysis was used. The changepoint method shows an interesting concept for detecting obstacles during a walking route. Several locations can be indicated where the changepoints in the walking behaviour (speed), the slope of the location, and the accelerometer behaviour fall together and could indicate a large obstacle like a curb. See detailed map (c) in figure4.9 and detailed map (b) and (c) in figure4.12. Peaks in the acceleration of the z-axis are located around imperfections in the pavement and are not accompanied by speed changes, indicating a small obstacle, see map (b) in figure 4.9 and (c) in figure4.15. But also stops by the participant are included, figure 4.12. Overall it is interesting to notice that almost all changepoints can be explained through logical reasoning. In the speed time series of the Leica route all changepoints indicate a obstacle, curb, a break made by the rollator user or curves in the road. Also the changepoints in the z-axis acceleration in the walking route with the MeetRollator seem to be related to the true situation. However, poor GPS performance makes it hard to accurately compare the points location. Overall, on straight segments of the route where the pavement stays nearly the same and walking speed is continuous, less changepoints can be found. A high amount of incorrect slope changepoints originates from the previously mentioned inaccurate location determination which resulted in extracting values from the slope raster at the wrong location.

That the accelerometer did result in interesting changepoints at curbs and obstacles and clearly detected differences in surface characteristics shows that obstacle detection and surface quality monitoring is another possible application to the Smart Walker. By using the presented methodology more data can be gathered on the critical walkability factors for elderly with a rollator. It provides a method to easily map obstacles and pavement quality that can help for design reference evaluation and inventory. The goal of this research is to support the forgotten pedestrian in policy, research and data. By using these methods to map the walkability problems we raise more awareness and hope to trigger possible action at decentralized governments to increase walkability quality and so increase walking activity of elderly people. To keep them fit and healthy, capable to live independently and grow old in their own house and environment. All contributing to less need for healthcare to the growing share of elder population and reduce the cost of elder care.

5.2. Discussion

We concluded that the accelerometer together with GPS attached to a rollator provides an interesting approach to measuring and locating obstacles during a walking route. However, the process of this research and the methods used may have many pitfalls, influencing the accuracy of the outcome. In this section we discuss the methods and the results.

5.2.1. The forgotten pedestrian

Policy design documents state that the pedestrian area is often the residual area in design with the least priority. This was confirmed by the contacts from the municipality giving arguments that the pedestrian is forgotten in design. This refers to the total group of pedestrians, not specifically the mobility impaired pedestrians, who even require a better designed public space. Our contact persons at the municipality could not tell if any geodata was available on pedestrians or who could provide it. This could mean several things: first of all, the data does exist and the people we spoke to, working on the design of the public space, are not aware of possible data. Confirming that the pedestrian is forgotten in policy design and data is scattered and not well organized. Second, the data does exist but we had the wrong contact persons at the municipality. Final option: the data does really not exist. This confirms the forgotten pedestrian in data like the PQN report states that there is not enough data on pedestrians [38].

Matthews et al. (2003) [30] also encounters this problem, in specific that no data is held on pavement centrelines. The basic layer for a GIS model is to know what is pedestrian area or not. Our own research confirmed that the GBKA, the most detailed topology dataset of the municipality of Amsterdam, did not contain a label on roads to determine whether it was a road for cars or a pavement for pedestrians. In order to find the pedestrian in data we conducted our own analysis of general assumptions to label the pedestrian polygons. This task proved itself more difficult than expected. The developed approach showed a lot of wrongly classified segments because many assumptions caused wrong classification. For example, not all parking lots are suitable for walking. Bridges often have pavement on either side, but are not detected in the approach for they rarely contain street furniture and are not adjacent to buildings. Matthews suggest to map precise pedestrian routes manually, but this was not done for this study as it was too time consuming [30].

5.2.2. Collecting the user perception

As Stahl et al. 2008 stated, user involvement leads to research of grater relevance to people and the findings more likely to be implemented [41]. Their research is based on the problems identified by elderly people and therefore of great relevance. Also for this study the involvement of elderly with a rollator was perceived as important. For the conducting researcher to be young and not having any experiences with mobility problems, it was key to hear from first hand. The first intention of our research was to interview at least 20 elderly in Amsterdam that walk outside regularly with a rollator. Unfortunately, this was harder than expected. Elderly care houses were not keen on cooperating. Calling would often result in a redirection to the location manager and no answer to the e-mails. Some institutions did show some enthusiasm: The Flessenman and De Tweede Uitleg, were willing to cooperate but could only provide 3 participants who walked outside with the rollator from which 2 were available for interviewing. The Buurtzorg Centrum were also enthusiastic. But after several calls and e-mails they never responded with possible contacts for participants. In the end the short and quick interviews at the Rollatorloop gave more insight. The participants that did cooperate showed how strong the influence of the personal preferences is on the perception to the surroundings. One of the participant really likes walking while the other rather stayed inside. This strongly influenced their feelings and emotions they had to walking outside. The presence of differences in rollator users and personal determinants should also be taken into account for walkability research.

Another interesting question is why elderly people in the care house did not go outside? The Flessenman counts 183 rooms [2] and the caregivers only responded with 3 participants that walked outside regularly, which is a small number. This however was not asked for or looked into during this research.

5.2.3. The Accelerometer sensor of a Smart phone

Next to different rollator users there are also a lot of different rollators. This research did not take into account the many types of rollators available. The type of wheels and structure of frame might influence the measurements and can result in different data characteristics if multiple rollators are used.

The application, Physics Toolbox Accelerometer, showed good results and was easy to use for measuring the accelerometer sensor of the phone. However, the first versions of the application stopped measuring when the phone went in sleeping mode. The test set-up showed imperfections caused by a lack of experience for the conducting researcher was not familiar with these kind of datasets. The test data could have been explored better un the first stage for the missing data gaps, when the phone went in sleeping mode, could have been detected earlier. After a quick analysis assumed was that the sensor had a malfunction for example, heavy movements cause the sensor to overload. After the first experiments failed, a more in depth research of the application behaviour and its settings, including contacting the developer, was done. This resulted in more controlled knowledge about the performance of the application. After the application version change and the improvement of the application it was perfectly working and gave no further problems.

The accuracy or errors from the accelerometer are unknown, as the quality of the sensor in the phone is unknown and not researched. The exact meaning of the value range given by the application are unknown and can differ per phone device.cite devleoper This could be relevant if our data has to be compared to other measurements and methodologies. Within our own study, the values are all relative to each other and can be compared. Also, observation of the measurements showed credible outcomes because the derived changepoints showed a realistic situation. This was confirmed by putting the accelerometer flat on the table which did not show any abnormal peaks or deviations.

The comparison with Matthews et al. /citeMatthews2003 showed a moderate correlation. The measurement methods are different and the exact type of surfaces used by Matthews unknown. A correlation for a linear increase in the variation per surface type can be seen in both data sets. Matthews measured surface hindrance and we measured the vibration effects on the rollator, both can be seen as a measure of the roughness of the surface.

5.2.4. Influenced experiments

After the measurements failed, we conducted some additional walks with the MeetRollator. This could give a wrong image on the measured walking behaviour outcome. From Wang et al.(2015) we learned that there is no difference in walking gait characteristics between elderly and young people [48]. But elderly are more used to handling a rollator compared to young people, for which a rollator could be an obstacle in moving more easily. Walking with the rollator myself could therefore have influenced the outcomes.

5.2.5. Spatial accuracy in data and measurements

The locations measured with the smart phone or the Garmin summit are not accurate enough to detect the location on a few centimetres exact. This resulted in wrong extraction of data values from the AHN2 and the slope raster. Many slope changepoints cannot be used to form a conclusion.Also the detected changepoints from this dataset which are mapped with the location measurements did therefore not represent the true location where they occur. In order to detect exactly where a route was walked, a good location determination is needed. The detail required, is almost on stone level. The measurements is not useful for walkability studies if it cannot be determined if someone is walking on the right side of the street or the left. Also on pavement level the presence of put-holes or curbs is of significant importance. The Leica system can detect the location on a few centimetres accuracy. But it is a heavy system which cannot be easily mounted on a rollator without influencing the rollator control and movement. It could possibly cause a dangerous situation for the elderly depending on it.

The slope map resulted in classifying most pedestrian area as unsuitable, for it contained an average slope of above 4%. This was influenced by the polygons of the pedestrian area including the curbs, instead of placing the curbs on the road sections. Also building edges not being cleaned out in detail enough can result in very high slopes in some pixels, resulting in an average slope which is way too high. The AHN2 dataset which was used is cleaned from parked cars and trees but obstacles or bikes parked on the pavement are not erased. This also, can cause an average slope that is too high. Overall, the AHN2 has a resolution of $0.5m^2$ and a precision of systematic and stochastic error of max $5cm$ [44]. Which makes it detailed enough for mapping pavement slope and curb detection.

Mapping the accelerometer points with the GPS was done in the RDnew projection and could therefore be easily approached with a linear relation. The accuracy of the GPS measurements is again the accuracy of mapping the changepoints. For this is the starting point where the time and distance difference is key. Here we assume the measured time of the accelerometer and the GPS are to the millisecond accurate.

5.2.6. The Changepoint method

The changepoint detection methods as provided by Killick et al. [26] was an unknown method to the conducted researcher and her supervisors. When first encountering the method it showed a lot of potential and interesting opportunities to analyse statistical route characteristics.

First, the possible settings in the changepoint package of R had to be explored. Killick et al. [26] provides several algorithms and penalty settings. The reliability of the changepoint detection depends on the algorithm choices and settings and greatly influence the accuracy. Because there are many different possibilities ours is maybe not the best. Next to this, missing data gaps were filled in with an average value, influencing the time series characteristics. The changepoint detection did provide a quick and easy to compute method to find statistical changes in the time series data. The accuracy of the detected changepoints can only be checked if the location is also accurately determined. Now, we can only assume that the indicated events found are associated with obstacles like a curb.

The urban environment will never be optimal and certain changepoints will indicate not so important happenings.

The start of walking with a firm push against the rollator will also show. By this, also a break on the street will also show as a changepoint in speed and vertical acceleration.

deviations in the measurements: starten met lopen, is een harde duw tegen de rollator? waardoor er een piek in de accelerometer data ontstaat.

Provide a quicker way to detect obstacles

5.3. Recommendations

Recommendations to improve the methodology:

- Conduct a more structured interview methodology related to specific routes and critical factor analysis, with elderly living in Amsterdam and walking with a rollator outdoors, to get a better understanding of location specific problems.

- Conduct the walking routes with elderly again, and more, with the Leica and a good working accelerometer application.

- In order to conduct a better pedestrian area classification, it would have been better not to include parking lots into the pedestrian area. Comparing the classification methods with manual classification could have said more about the accuracy of the method.

- Conduct more controlled experiments with elderly themselves. Also comparing routes walked in a controlled environment against routes walked in the real living environment. This can give better insights if this methods works for detecting obstacles along the real walking routes of elderly, when walked by themselves. Instead of a young vital person walking with a rollator.

- Use more precise GPS systems, like the Leica system for location determination. The detail for which the detection of obstacles is needed, has to be very precise. The slightest deviation can give falsehoods in the changepoint detection for slope. Another possibility is the method used in the research of Wang et al. [48]. Here they use an accelerometer exactly placed on the rollator to monitor the displacement for every step made. By using this method the route of a person could be exactly determined from the starting point, with an accuracy of about 1 cm and no GPS would be needed. This would require a standardized measurement rollator were the exact distances of the sensor to the wheels and frame is known.

- More research to the application and possibilities of the AHN2 can be interesting for mapping walkability. The accuracy of the AHN2 is detailed enough to map the presence of curbs. It would be interesting to see if it can also map the height of curbs, another critical walkability factor that is of importance for elderly with a rollator.

Recommendations for future research:

- Quantify the relation between surface hindrance and the effort needed for elderly with a rollator to walk on. For example measuring energy use of elderly. Also the perception of elderly to different surface circumstances could be measured. An interesting link could be the report from Hogertz et al. 2010 [38], which tries to measure skin conductivity as a quantitative measure for arousal.

  Possible applications of smart phone with accelerometer use, for measuring rollator movements or surface resistance. Translate this to the amount of energy that elderly consume. Wattage of elderly people.

- Possible applications might be to detect the kind of surface material from the accelerometer signatures. Create a specific signature for a specific surface material. Different sets of rollators might react differently to surface irregularities and has to be taken into account.

- This study could be used to create a low cost, non-intrusive method for identifying the location of obstacles on the route of elderly with a rollator. A more in detail method could be designed, that automatically filters out priority obstacles where the data changes in a specific way.

- using the changepoint method and regarding a route as a time series dataset could be an interesting method to detect walking behaviour, driving behaviour changes.
- Bartholomew in recommendation future research. Map more determinants to get more insight in the total picture. figure 2.1. zie opmerking. Link naar de figuur.
- A final but essential recommendation is, detecting wrongly parked bikes and cars. Set up a program to raise more awareness of citizens about the problems they cause when parking their bikes wrong. I noticed I never thought about the placement of my bike in relation to the rest of the pavement until I started this project. It makes you look with different eyes and makes you more aware of where to park your bike so enough space is left for others to pass through.

5.4. Final words

It is proven that for elderly, who are more vulnerable, environmental attributes can be barriers to an active engagement in urban life. The quality of the immediate environment is a significant determinant of elders well-being, independence and quality of life. Developing ways to quantify their problems and add more data on their walkability quality could lead to more insight and hopefully to interventions on pavement level. In the near future, there will be more elderly who are willing to live independently and grow old in their own home. In order to facilitate this, we have to look forward and adapt the environment now when we are still young.